THE DEVELOPMENT OF DURABLE ASPHALT PAVEMENT USING MODIFIED POLYMERS AND RESOL AS REINFORCING MATERIALS

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Abstract

Asphalt is predominantly used to construct pavements for roads, highways, and airports. Both asphalt binder and asphalt – aggregate mixture show temperature and time dependent behavior. Rutting or permanent deformation is the leading cause of pavement deterioration in temperature and warm climatic regions of the world and low – temperature cracking is a common problem in cold regions. As the highway pavement infrastructure has aged and deteriorated, more pavements are in need of maintenance, rehabilitation, and reconstruction. This is traditionally done by placing hot mix asphalt overlay.

Four contents of crumb rubber, waste plastic, polyvinyl alcohol, and resol are used. These are (2.5, 5.5, 8.0, 10.5)% by weight of aggregate, three contents of crumb rubber, waste plastic, polyvinyl alcohol, and resol are used as additives to asphalt cement represent about 1.3% from the percentage of asphalt cement. It was found that the addition of crumb rubber, waste plastic, polyvinyl alcohol, and resol increased the Marshall stability retained strength, and air voids.

Resol and crumb rubber gave rise higher values of Marshall stability than waste plastic and polyvinyl alcohol. The study also allowed for the identification of many important engineering concerns which must be addressed in future, and more extensive, studies in this area.

تطوير اسفلت التبليط المتين باستخدام البوليمرات المعدلة والريزول كمواد مقوية

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الخلاصة

يستخدم الإسفلت في بناء الطرق والممرات السريعة ومدارج المطارات، أن صفات كل من الإسفلت الرابط وخليط ركام الإسفلت تعتمد على درجة الحرارة والفترة الزمنية للاستعمال. أن أثر عجلات السيارات والتشوه الدائم هو السبب المؤدي إلى تلف الطرق المبلطة بشكل مفرط في المناطق الحارة ومناطق الدفء المناخي في العالم وان التكسر الناتج من درجة الحرارة الواطئة هو مشكلة مألوفة في المناطق الباردة. وبما إن البنى التحتية

للطرق المبلطة السريعة أصبحت قديمة وتالفة لذلك فقد برزت الحاجة إلى إدامة تبليط الطرق وإعادة تأهيلها وبناءها. وعادةً ما يتم ذلك بالطرق التقليدية من خلال أكسائها بطبقة من خليط الإسفلت الحار.

أن أربع كميات من مسحوقي المطاط المستهلك وفضلات البلاستك وبولي فنايل الكحول والريزول تم استخدامها وهي (٢.٥ ، ٥.٥ ، ٨.٠ ، ١٠.٥)% من وزن الركام ، وقد تم استخدام ثلاثة كميات من مسحوقي المطاط المستهلك وفضلات البلاستك وبولي فنايل الكحول والريزول كمواد إضافة إلى إسفلت الاسمنت وقد مثلت بحوالي ١.٣% من نسبة إسفلت الاسمنت. وقد تم التوصل إلى أن إضافة مسحوق المطاط المستهلك وفضلات البلاستك وبولي فنايل الكحول والريزول يزيد من استقرارية المارشال وقوة الاستبقاء والفجوات الهوائية. يعطي كل من الريزول ومسحوق المطاط المستهلك قيم عالية من استقرارية المارشال أكثر من فضلات البلاستك وبولي فنايل الكحول.و توضح الدراسة ايضاً تعريف الكثير من الأمور الهندسية المهمة التي يجب التعرف عليها في المستقبل ودراسات مكثفة في هذا المجال.

Introduction

Considering both road application and "in life" service, asphalt can be subjected to temperatures ranging from many degrees below zero to about 190-200 °C The glass transition region of asphalt usually starts at temperatures of about -20 °C, and the Newtonian region may start at temperatures of about70 °C.

In relation to the road application, the different viscoelastic behavior of asphalt leads to different defects in the paved surface[1]. At usual summer temperatures of pavement surface (60 °C), under traffic load, asphalt is not able to maintain the original shape of the pavement, thus leading to permanent deformation known as rutting. In low temperatures, the asphalt gets brittle and tends to crack, because the stiffer structure is unable to relax the internal stresses originating from traffic load[2]. Both of these distresses are not avoidable for neat asphalt, resulting in a shorter pavement lifetime. To overcome these problems various modification of the neat asphalt are studied. For the sake of brevity, we will here discuss the polymer modification only. The idea of such modification is essentially to improve the mechanical properties of the binder, which are supposed to become similar to the ones of the modifying polymer. This is usually obtained by adding from 2 to 8%wt of polymer on the total mass of the HMA[3]. Polymers can be added, which modify the natural viscoelastic behavior of the asphalt cement; thus affecting the ideal temperature range. There are two main classes of polymers used for this purpose: elastomers, which enhance strength at high temperatures; as well as elasticity at low temperatures; and plastomers, which enhance strength but no elasticity [4]. The large – scale use of these polymers may be attributed to their networks, which are due to the rheologic properties of the modified binder and the interactions of bitumen constituent that increase the complex modulus and the elastic response[5].

The modification has to be done with respect to some requirements. First of all, of course, the modification has to be cost effective (reduced maintenance costs has to be taken in account). Secondly, a good compatibility with neat asphalt is required, especially in case of road paving, where high temperature storage specifications define temperature and period of storage during which the polymer should not separate from the binder [6].

This work concentrates on the study of the asphalt mixture of surface course for express way to achieve specific mixtures from asphalt concrete based on different fillers, resol, and polymers to optimize the effect of the types and variations of various non bituminous materials on the Marshall properties, air voids, and index of retained strength of asphalt mixture concrete.

Materials and Experimental Techniques

1. Materials

1.1 Asphalt Cement

In this work, the asphalt cement type was used: (60 – 70) penetration grade taken from Daurah refinery. The asphalt cement types characterized as D67 where the number after letter refers to the penetration value of asphalt grade. Original asphalt cement types are tested to determine their physical properties such as: penetration and absolute viscosity (consistency), softening point (heating temperature), ductility (tensile properties) and mass loss (durability and aging). The test used to determine these properties are now common and convention and don't need more description. The physical properties of different original asphalt types are presented in Table (1).

Table 1: Physical Properties of Asphalt Cement

Test	Unit	Penetration Grade	
		(40 – 50)	(60 – 70)
Penetration on (25°C, 100g, 5 s),ASTMD5	1/10 mm	40	65
Absolute viscosity at 60°C, ASTM D2171	poise	2065	1585
Kinematics viscosity at 135°C, ASTMD2170	poise	430	340
Ductility (25°C, 5 cm/min), ASTM D113	cm	>150	>150
Softening point (R&B),ASTM D36	°C	52	47.78
Specific gravity at 25°C, ASTM D70	Gm/cm^3	1.045	1.04
Flash point, ASTM D92	°C	273	256
After thin-film oven test, ASTM D1754 / Penetration of residue(25°C, 100g, 5 s), ASTM D5	1/10 mm	33	39
Ductility of residue (25°C, 5 cm/min) ASTMD113	cm	>100	>100
Loss in weight (163°C, 50 gm, 5hrs) ASTMD2754	%	0.183	0.224

1.2 Octyl phenolic butyl curing resin (vulcaresin)

Composition:

A heat reactive methylol alkylated formaldehyde resin specifically formulated for curing butyl or halogenated butyl compounds.

General description

Available as lumps (up to 5 cm) or 12 mesh powder (up to 1.5 mm).

Specific gravity (typical) g/cm^3 1.04

Characteristics units requirements Infrared spectrum comparable with standard

Acid value mg KOH/g 10 – 30

Methylol content % 8.5 ± 1

Loss on heating to 65°C % 0.5 maximum

Ash at 550°C % 0.5 maximum

Softening point C° 90 – 95

1.3 Crumb Rubber

Crumb rubber produced from whole tyres in which the rubber hydrocarbon may be NR, IR, SBR and BR.

The crumb rubber has the following characteristics:-

Specific gravity (typical) 1.15 g/cm^3

Characteristics	**requirements**
Bulk density	**1.15**
Carbon black	**1.74**
Polymer base, N/S/B	**60/20/20**
Rubber %	**65.82**
Carbon black, %	**28.77**
Ash, %	**5.41**
Total, %	**100.00**

1.4 Waste Plastic is indefinite type.

1.5 Polyvinyl Alcohol

The polyvinyl alcohol is used in this work. The properties of polyvinyl alcohol is listed as follow:

Density 1.19 – 1.31 g/cm^3

M.W. Approximately 14,000 g/mol

Melting point (decomposes): 200 – 267 C°

Flash point 79 C°

Mixing Procedure

The mixing procedure represents the procedure used in preparing asphalt mixtures

involved in current investigation. The efficiency of mixing procedure depends on providing homogenous mix and uniform coating of aggregate with asphalt. Asphalt mixtures were prepared in this investigation as follows:
The aggregates were first separated in two desired sizes as well as filler to achieve grading requirements of SCRB[7] specifications for surface course. Each size of aggregates was washed and then dried to constant weight in the oven at 110 ± 5 °C. The weight of each aggregate size and filler was determined from multiplying its percent by desired weight of final mixture. All aggregate sizes and filler were placed in mixing bowel. The aggregates and filler were then heated to temperature of 160 °C before mixing with asphalt cement (60 – 70), and penetration grade asphalt cement were heated in oven to the temperature of 145 °C and 150 °C respectively. The asphalt cement was weighed to the desired amount and then added to the heated aggregates and filler in the mixing bowl. All components were mixed thoroughly until all aggregate and filler particles were completely coated with asphalt. The mixing temperature was maintained within required limits (115 – 155) °C for (60 – 70) penetration grade asphalt cement respectively.

Preparation of Marshall Specimens

This step includes preparation of cylindrical specimens which were (101.6 mm) in diameter and (63.5 ± 1.27 mm) in height in accordance with method ASTMD1559[8]. The procedure used in the investigation to prepare Marshall Specimens for asphalt concrete mixes can be described as follows:

The Marshall mould assembly (101.6 mm) in diameter by (76.2 mm) in height spatula, and compaction hammer were heated on hot plate to temperature between (90 and 150 °C). The asphalt mixture was placed in the preheated melt and it was then spread vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior. The temperature of the mixture immediately prior to compaction was between (140 – 150 °C). Then 75 blows on the top and bottom of the specimen were applied with a compaction hammer of 4.535 kg sliding weight, and a free fall in (457. 2 mm). The specimen in mold was left to cool at room temperature for 24 hours and then it was removed from mold. Three Marshall specimens were prepared at each asphalt content. Thus, 15 specimens were prepared for five asphalt contents and for each asphalt mixture type.

Resin Modified Asphalt

1. In the asphalt – resin mixtures the vulcaresin represents about 1.3% of the percent of the binder. Blending of vulcaresin with the asphalt is expected to take between 45 minutes and one hour at 190 °C to achieve the reaction necessary to provide desirable binder properties. After blending of asphalt, with vulcaresin and diluents is completed with aggregates can proceed as with conventional HMA, however temperature of the blending must remain above 190 °C during the mixing and discharge operation.

2. In the resin – modified mixtures the granulated vulcaresin is hundred like an aggregate and fed into the plant through the cold feed system. The dry granulated vulcaresin particles are mixed with the aggregate prior to mixing with asphalt in quantities ranging from 2.5 to 10.5 percent by weight of the aggregates. However temperature must remain above 190 °C for one hour until a stabile viscosity is achieved. The vulcaresin grading is listed in Table 2.

Table 2: Vulcaresin resin grading

Sieve size	% passing
3/4	100
1/2	90 – 100
3/8	77 – 93
No. 4	44 – 74
No. 8	29 – 58
No. 16	21 – 46
No. 30	12 – 33
No. 50	5 – 21
No. 100	4 – 15

Rubber Modified Asphalt

The procedures follow as resin modified asphalt above.
The crumb rubber grading is listed in Table 3.

Table 3: Crumb rubber resin grading

Sieve size	% passing
3/4	100
1/2	90 – 100
3/8	77 – 93
No. 4	44 – 74
No. 8	29 – 58
No. 16	21 – 46
No. 30	12 – 33

Plastic Modified Asphalt

The procedures follow as resin modified asphalt above.

The waste plastic rubber grading is listed in Table 4.

Table 4: Plastic resin grading

Sieve size	% passing
3/4	100
1/2	90 – 100
3/8	77 – 93

Polyvinyl Alcohol Modified Asphalt

The procedures follow as resin modified asphalt above.
The waste plastic rubber grading is listed in Table 5.

Table 5: Polyvinyl alcohol resin grading

Sieve size	% passing
3/4	100
1/2	90 – 100
3/8	77 – 93
No. 4	44 – 74
No. 8	29 – 58
No. 16	21 – 46
No. 30	12 – 33
No. 50	5 – 21
No. 100	4 – 15

Calculation of the Percentage of Voids in Total Mix (VTM) in each Compacted Specimen

This is the volume of the small pockets of air between the coated aggregate particles throughout the compacted mixture. It is obtained by first determining the maximum theoretical density of the specimen and then expressing the different between this and the bulk density as a percentage of the theoretical density. The maximum theoretical density can be measured for the asphalt mixtures at each asphalt content by using the standard method under designation of ASTM D2041[8]. The percentage of voids in total mix (% VTM) in the compacted specimen is obtained from the following equation:

$$\%VTM = \frac{\psi_t - G_{mb}}{\psi_t}$$

Where:
%VTM = voids in total mix, i.e., in the specimen (%).
ψ_t = maximum theoretical density (g/cm^3).
G_{mb} = average bulk density (g/cm^3).

Determination of Marshall Stability and Flow of each Specimen

The Marshall stability and flow test is performed on each specimen, which was tested for bulk density, in accordance with procedure described by ASTMD1559[8] for “Resistance to the plastic flow of bituminous mixtures” using Marshall apparatus. It is type of unconfined compressive strength test in which the test specimen is placed in water bath at 60 °C for 30 to 40 minutes and specimen is then compressed radically at a constant rate of strain of 50.8 mm per minute. The Marshall stability of test specimen is the maximum load, in (KN) required to procedure failure while the stability test is in progress, a dial gauge is used to measure the vertical deformation of the specimen; the deformation read at the load failure point is the flow volume, in (mm), of the specimen.

Index of Retained Strength Test

Index of retained test is to evaluate moisture damage of asphalt pavement. The loss in Marshall stability is obtained by divided average of three Marshall specimen stability values soaking in water bath at 60 °C temperature after 24 hours by average of three Marshall specimen stability values soaking in water bath at 60 °C after 30 to 40 minutes. The Marshall stability loss must be not less 25% for surface course mixture.

Results and Discussion

Bulk Specific Gravity

Before performing the density – voids analysis the bulk specific gravity of the specimen must be determined. The specific gravity is obtained by dividing the specimen’s weight in air by its volume.
The magnitude of these values achieved during compaction in the laboratory is not of great importance. The main purpose of calculating these values is for their use in the density – voids analysis. It should be noted that the numbers vary very slightly, decreasing with increasing crumb rubber, waste plastic, polyvinyl alcohol, and resol.

Density – Voids Analysis

Two properties of the compacted are determined in the density – voids analysis: the air voids percent in the total mixture. The air

voids percentage represents the value obtained by subtracting the maximum theoretical density of the specimen from the average bulk density multiplying by 100 and then dividing by maximum theoretical density.
The air void% in a compacted specimen is suggested by most agencies to be between 3 and 5%. Low air void% is important in order to minimize the aging of the asphalt cement films within the aggregate mass and also minimize the possibility that water can get into the mix, penetrate the thin asphalt cement off the aggregates[9].
In general the air void% increased with increasing contents of crumb rubber, waste plastic, polyvinyl alcohol, and resol. The values are presented in Tables (6) to (11). However the air voids% of specimens with crumb rubber, waste plastic, polyvinyl alcohol, and resol is substantially higher than the control value. This could be due to the tendency of crumb rubber, waste plastic, polyvinyl alcohol, and resol to clump together and to lower density of these materials. Overall these results were as expected. The values are close enough to the suggested range to be acceptable and further optimization of the mixture design could easily bring the value within the specified limits.

Effect of Crumb Rubber Modified Mixtures on Asphalt Concrete

Introduction of scrap tire rubber into asphalt concrete pavement has the potential to solve this waste problem. It has been estimated that if only 10% of all asphalt pavement laid each year in United States contained 3% rubber, all the scrap tires produced for that year in this country would be consumed [10].
The dry process uses rubber as aggregate. Usually 2% to 3% rubber is added as a solid, with coarse and fine aggregates to a pure asphalt binder. The most popular mix design for this product has been patented under the trade name "Plus Ride"[11]. Most of the asphalt – rubber research work done in the past concentrated on roads with hot mix asphalt (HMA) concrete with finely ground rubber, commonly known as crumb rubber. This crumb rubber is expensive, and would not be cost effective for low volume roads. The use of crumb rubber as aggregate results in an improvement in asphalt concrete such as resistance to rutting, fatigue cracking and thermal cracking, in addition to protecting the environment and saving resources[12].
Four crumb rubber contents are used. These are 2.5, 5.5, 8.0, and 10.5 percent by weight of aggregates. The purpose of this process is to examine the influence of crumb rubber with different contents on the Marshall properties, bulk density and air voids.
As shown in Table (6), the Marshall stability, for two mixtures, increases to a certain point in which it starts decreasing with increasing crumb rubber content. Bulk density decreases and air voids increases as the content of crumb rubber increases.
The idea of such modification is essentially to improve the mechanical properties of the asphalt concrete, which are supposed to become similar to the ones of the modifying rubber. The crumb rubber has to be done good compatibility with neat asphalt is required, especially in case of road paving, where high temperature storage specifications [13].
On the other hand, the crumb rubber may produce a linked network of polymeric macromolecules with asphalt. In this case the asphalt is trapped within a net of elastic, which are linked together with functional groups of crumb rubber and therefore lead to an elastomeric behavior of the binder providing more resistance to damaging effects of water and temperature.

Effect of Waste Plastic Modified Mixtures on Asphalt Concrete

In recent years, plastics have experienced substantial growth and acceptance as a replacement for many materials. The growth of plastics in the bottling and packaging industry has been exceptionally steep. Plastics also continue to make up an increasingly large share of the floor coverings market.
These two plastics applications, as well as others, have produced large quantities of consumer post – use and scrap plastic materials. There are entire industries whose efforts are directed to finding favorable economic and ecological uses for these scrap and recycle plastic materials. This work is directed, in part, to the use of waste plastic material as an additive which improves asphalt properties and provides an environmentally acceptable method for recycle of post consumer carpet and bottles.
Four waste plastic contents are used. These are 2.5, 5.5, 8.0, and 10.5 percent by weight of aggregates. The purpose of this Process it to examine the influence of waste plastic with

different contents on the Marshall properties, bulk density and air voids.

As shown in Table (7), the Marshall stability, for two mixtures, increases to a certain point in which it starts decreasing with increasing waste plastic content. Bulk density decreases and air void increases as the content of waste plastic increases.

The present work provides an improved Polymer additive which may be used to increase the high temperature viscosity of asphalt, without deleterious affecting the low – temperature viscosity of the asphalt. The Waste plastic may also used to improve the stiffness of certain asphalt.

Effect of Polyvinyl Alcohol Modified Mixtures on Asphalt Concrete

In order to certify the effect of polyvinyl alcohol on Marshall properties of asphalt concrete mixture. The following four contents are used: 2.5, 5.5, 8.0, and 10.5 percent by weight of aggregate.

As shown in Table (8) the Marshall stability, for three mixtures, increasing to a certain point after which it starts decreasing with increasing polyvinyl alcohol content. Bulk density decreases and air void increases as the polyvinyl alcohol content increases.

The use of polyvinyl alcohol as additive, via chemical or physical blending has been shown to greatly improve the performance of conventional asphalt. The nature of polyvinyl alcohol has displayed to combine properties of elasticity, strength and adhesion to increase road life. Improved properties also include greater resistance to aging and stability at high temperature.

Effect of Asphalt Polymer Modified Types (Crumb Rubber, Waste Plastic, and Polyvinyl Alcohol) Mixes on Asphalt Concrete

In the asphalt – polymer mixtures three types of polymers (Crumb rubber waste plastic and poly vinyl alcohol) are used as additives in this work to investigate the influence of polymer modified type asphalt on asphalt concrete. The polymer represents about 1.3% of the binder percentage (asphalt cement).

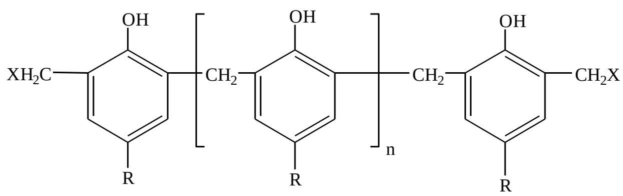
As shown in Table (9) the Marshall stability of crumb rubber is higher than waste plastic and polyvinyl alcohol. Bulk density of waste plastic is higher than polyvinyl alcohol and crumb rubber, while air voids of polyvinyl alcohol is higher than waste plastic and crumb rubber.

Polymers are the most common modifiers currently being used to improve asphalt cement viscoelastic properties. The polymers increase the temperature range over which a binder resists both rutting and thermal cracking as well as lengthening the time before fatigue failure[15].

Polymer – modified binders typically are more viscous (thicker) than unmodified binders, and tend to show improved adhesive bonding to aggregate particles (sticker). These properties result in a thicker binder coating on the aggregate particles that does a better job of holding the particles together. The better adhesion helps to minimize drain down at the time of construction, and also helps to reduce the tendency of the pavement to revel once it has aged.

Effect of Vulcaresin (Resol) Modified Mixture on Asphalt Concrete

Resols are usually made from phenol – formaldehyde resin which is a molar excess of the aldehyde. They differ from novolaks in that they contain methylol groups, dibenzyl hemiformal or dibenzyl ether groups instead of the simple methylene bridges between the benzene rings[16].



n = 0, 1, 2
X = OH, Halogen
R = Hydrocarbon residue

Four vulcaresin contents are used. These are 2.5, 5.5, 8.0, and 10.5 percent by weight of the aggregate. The purpose of this process is to examine the influence of vulcaresin with different contents on Marshall properties, bulk density, and air voids.

As shown in Table (10) the Marshall stability, for these mixes, increases to a certain point after which it start decreasing with increasing vulcaresin content. Bulk density decreases and air voids increases as the content of vulcaresin increases.

Heating causes the reactive molecules of vulcaresin in to condense, through the reaction of methylol groups with asphalt, to stable methylene links. Water is eliminated during this reaction. The rate of reaction depend on temperature, resol acidity, structure, free phenol, formaldehyde contents and resol moisture content. Improved properties also include greater resistance to aging and stability at high temperatures to increase road life.

Effect of asphalt vulcaresin mixture on the asphalt mixture concrete

The resol modified asphalt is a new technology which provides many of the performance characteristics of asphalt cement with the economy and ease of construction of an asphalt concrete pavement.

In the asphalt vulcaresin mixture, one type of resol is used as additive in this work to investigate the influence of vulcaresin modified on asphalt concrete. The vulcaresin represents about 1.3% of the binder percentage (asphalt cement).

As shown in Table (11) the Marshall stability of vulcaresin is higher than polymers asphalt mixes which provides fuel – resistance and rut – resistance requires little to no maintenance, and requires much less cost and effort to construct when compared to ordinary asphalt concrete mixture.

Comparison of Index of Retained Strength

The average stability values of the three specimen immersed in water bath at 60ºC for 24 hours divided by average stability values of three Marshall specimens immersed in water bath at 60ºC for (30 – 40 min.) is referred to index of retained strength (I.R.S). The Marshall stability loss must be not less than 25% for surface course mixture as shown in Tables (12) and (13).

Conclusions

The following conclusions are derived from this study:

1- Improving low temperature flexibility exhibited by increased elongation that allows the pavement to yield without fracturing.
2- Better resistance to flow or creep at elevated temperatures and greater resistance to oxidative hardening due to the presence of rubber antioxidants.
3- Improved polymer additive which may be used to increase the high temperature viscosity of asphalt, without deleteriously affecting the low – temperature viscosity of the asphalt.
4- Marshall stabilities 0f crumb rubber, waste plastic, polyvinyl alcohol, and resol mixtures, increases to a certain point which it starts decreasing with increasing polymers and resol contents.
5- Adding the scrap plastic may actually improve the quality of the paving.

Utilization of waste plastic in bituminous concrete mixtures provides increasing resistance to rutting and water damages

6- Incorporation of crumb rubber to bituminous mixes requires a slight increase in the optimum binder content.
7- Improved strength retention when wet that may result from the effects of rubber additives (sulfur accelerators and zinc compounds) which may promote better adhesion with the aggregate through slow migration of surface active components to the interface.
8- Use of polyvinyl alcohol improves the performance of conventional asphalt, greater resistance to aging and stability at high temperature.
9- Utilization of polyvinyl alcohol in asphalt cement reduces the tendency of the pavement to reveal once it has aged.
10- Methylol groups of vulcaresin reacts with asphalt to form methylene linkages leads to increase in resistance to aging and stability at high temperature.
11- Marshall stability of vulcaresin modified mixture is higher than polymer modified mixtures.
12- sphalt vulcaresin mixture provides fuel – resistance, rutting – resistance, and requires much less cost and effort to construct when compared to ordinary asphalt concrete mixture.

An important consideration is the effect of incorporation such as crumb rubber, waste plastic, polyvinyl alcohol, and resol on the quality and performance of the hot mixture asphalt pavement of course it would not be economically feasible to complicate the production of asphalt pavements if the result was a pavement with shorter life and higher maintenance costs. The results of this study show that addition of these materials does not have any significant adverse effects on the properties of asphalt pavement specimens, and in many cases the additives improve important properties.

Table 6: Crumb rubber modified mixture test results at different crumb rubber contents.

crumb rubber content %	Bulk density gm/cm^3	Air voids %	Marshall stability (kN)	Marshall flow (mm)
2.5	2.24	3.7	48	3.8
5.5	2.23	4.2	52	3.6
8.0	2.21	4.8	36.5	3.9
10.5	2.20	5.2	27.3	2.7

Table 7: Waste Plastic modified mixture test results at different waste plastic contents.

Waste Plastic content %	Bulk density gm/cm^3	Air voids %	Marshall stability (kN)	Marshall flow (mm)
2.5	2.12	3.6	23.8	2.9
5.5	2.11	3.9	37.9	2.5
8.0	2.10	4.6	18.8	3.6
10.5	2.09	5.5	14.4	3.8

Table 8: Polyvinyl alcohol modified mixture test results at different polyvinyl alcohol contents.

polyvinyl alcohol content %	Bulk density gm/cm^3	Air voids %	Marshall stability (kN)	Marshall flow (mm)
2.5	2.29	3.9	13.21	3.8
5.5	2.25	4.3	16.34	3.6
8.0	2.23	4.8	18.72	3.3
10.5	2.20	5.4	9.85	4.8

Table 9: Asphalt polymer mixtures test results at different polymer types.

polymer modified types	Polymers% by weight of asphalt cement	Bulk density gm/cm^3	Air voids %	Marshall stability (kN)	Marshall flow (mm)
Crumb rubber	1.3	2.00	3.8	21.4	2.4
Waste plastic	1.3	2.16	4.0	16.32	2.0
Polyvinyl alcohol	1.3	2.12	4.9	12.92	2.7

Table 10: Vulcaresin modified mixture test results at different vulcaresin contents.

Vulcaresin content %	Bulk density gm/cm^3	Air voids %	Marshall stability (kN)	Marshall flow (mm)
2.5	2.26	3.4	61.9	3.8
5.5	2.24	3.9	63.2	3.3
8.0	2.19	4.4	76.7	3.7
10.5	2.15	4.8	50.5	4.8

Table 11: Asphalt vulcaresin mixture test results at vulcaresin content.

Resol type	Vulcaresin% by weight of asphalt cement	Bulk density gm/cm^3	Air voids %	Marshall stability (kN)	Marshall flow (mm)
Vulcaresin	1.3	2.30	3.7	49.5	3.5

Table 12: Asphalt nonbituminous mixtures test results at different nonbituminous types.

nonbituminous materials types	Nonbituminous% by weight of asphalt cement	Marshall stability at 60°C for 24 hours in water	Marshall stability at 60°C for (30 - 40 min) in water
Crumb rubber	1.3	18	21.4
Waste plastic	1.3	13.24	16.32
Polyvinyl alcohol	1.3	10.8	12.92
Vulcaresin	1.3	44.52	49.5

Table 13: Nonbituminous modified mixtures test results at different nonbituminous types and contents.

nonbituminous materials types	Content %	Marshall stability at 60°C for 24 hours in water	Marshall stability at 60°C for (30 - 40 min) in water
Crumb rubber	5.5	43	52
Waste plastic	5.5	31	37.9
Polyvinyl alcohol	8.0	16	18.72
Vulcaresin	8.0	63	76.7

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