

THE INFLUENCE OF RESIN MODIFIERS ON THE PERFORMANCE OF HOT MIX ASPHALT

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ABSTRACT

In order to study the influence of resin modifiers materials on the performance of hot mix asphalts (HMA), two types of resin modifiers were selected. One was an Unsaturated Polyester Resin (UPR) and the other was an Epoxy Resin (ER). Also, unsaturated polyester resin mixed with 3% epoxy resin (UPRER) was used according to test results, which gave preference to 3% additions. Marshal test was conducted to study the stability, flow, bulk density, air voids (AV), voids in mineral aggregate (VMA) and voids filled with bitumen (VFA) for controlled hot asphalt mixtures and resin: modified mixtures at various resin modifiers contents. A computer program named BISAR was also used to determine the total stress, strain and displacement in x-y, and z-direction for flexible pavements constructed with these hot mix asphalts modified with resin additives. Experimental results showed that all resin-modified asphalt mixtures have higher flow, bulk density and VFA compared with control mixture. The stability of asphalt mixtures with UPRER was always higher than the control mixture. Unlike, for type ER and UPR the stability was lower than the control mixture up to 1% and 2% respectively then they increase. The UPRER gave higher stability, flow, AV and VMA than the other types. Moreover, the UPR gave the highest value of bulk density and VFA. The maximum stability occurs at 3% resin modifiers content for all types. The total stress and strain relatively increase with the increase of mix depth till 10 cm, then they decrease for all types of resin modifiers. The maximum total stresses and strain in case of UPRER are higher values than those achieved by ER and UPR respectively. The total displacement in case of UPRER is higher than that achieved by ER and UPR respectively. As resin modifiers can improve the field performance of asphalt mixes comprehensively, they will be of great benefit to the engineering field.

Keywords: hot asphalt mixes – modifiers– unsaturated polyester resin– epoxy resin – BISAR program.

1. Introduction

Modifying the asphalt mix by adding additives to the bitumen or asphalt mix has proved to help improve the performance of asphalt pavement efficiently. Among the modifiers of asphalt, fibers and polymers have gotten much attention for their expected excellent improvement effect. Various fiber and polymer modifiers, such as cellulose fiber, polyester fiber resin, epoxy resin, rock wool, fibrin and short asbestos and mineral fiber, have been widely used in different asphalt mixtures, including Stone Mastic Asphalt (SMA), Open Grade Friction Concrete (OGFC), etc[1-4].

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The polyester resin is an unsaturated thermosetting resin produced by a reaction between several organic acids and polyhydric alcohols. It is most commonly used in the construction of molded reinforced fiber and composite products. The unsaturated polyester resin used in most molding applications is a viscous liquid requiring the addition of catalysts and accelerators to complete the curing process. Epoxy resins are polymer materials that begin as liquids and chemically change into a solid [5]. The unsaturated polyester and epoxy are two types of resins which are used in this research to improve the performance of hot mix asphalts. The two types are liquid in forms.

Many former researches focused on the influence of fiber and polymer additives on the engineering properties of asphalt or asphalt mixture. Kwangetal. [6] made a study to investigate the possibility of utilizing a polyester resin for reinforcing flexible pavements. The application of a thin-layer coating with a polymer, unsaturated polyester resin (UPR) on the surface of a laboratory-prepared unmodified asphalt concrete mixture was studied as a tensile reinforcement method for such a material. Selected laboratory performance tests were conducted and the results were compared with those of a normal (uncoated) asphalt concrete mixture and a modified asphalt mixture. The polymer coating was found to be effective in improving Marshall stability, tensile strength and flexural strength of asphalt concrete.

Shopeng et al. [7] investigated the effects of polyester fibers on the rheological characteristics and fatigue properties of asphalt. The results indicated that the viscosity of asphalt binder had increased as the polyester fiber contents increased, especially at lower temperature. They confirmed that the fatigue property of asphalt mixture can be improved by adding fiber, especially at lower stress levels.

Maurer and Malasheskie [8] investigated the influence of fibers on overlay mixtures. Polyester was chosen over polypropylene because of its higher melting point. The study showed that the construction of the mixture was done without difficulty or extra equipment. The polyester fiber modified mixture was compared to several types of fiber reinforced segments and a control section, i.e. without any reinforcement. Test sections were rated for ease of construction, cost and resistance to reflection cracking.

Polypropylene fibers were used by Yi and Mc Daniel [10] in an attempt to reduce reflection cracking in an asphalt overlay. Although crack intensities were less on the fiber modified overlay sections, no reduction or delay in reflection cracking was observed. Sections in which the pavement had been cracked and set before the overlay were found to have less reflection cracking when fibers were used in either the base or binder layers.

WU et al. [11] conducted a dynamic modulus test and used the SuperPave simple performance tester (SPT) to study the dynamic modulus (E^*) and phase angle (δ) for the controlling asphalt mixture and fiber-modified mixtures at various temperatures and frequencies. Their results indicated that all fiber-modified asphalt mixtures have a higher dynamic modulus compared with control mixture. Also, fatigue and rutting-resistance properties can be improved by fiber additives. Chen and Lin [12] investigated the effect of cellulose, rock wool and polyester fiber on the engineering properties of asphalt, and the test results indicated that good adhesion between fibers and bitumen enhances the load-

carrying ability of asphalt-fiber mastics. Wu Shaopeng et al. [13] conducted the Dynamic Shear Rheometer (DSR) test to study the rheological properties of asphalt with various fibers. Their results indicated that the rutting-resistance property of asphalt with fibers could be improved to a large extent. Putman and Amirkhanian[14] compared the performance of Stone Matrix Asphalt (SMA) mixtures containing waste tire and carpet fibers with mixes made with commonly used cellulose and polyester fibers. The results revealed that the tire, carpet and polyester fibers significantly improved the toughness of the mixtures, but no significant difference in permanent deformation or moisture susceptibility was found. Zhu et al. [15] did a study to determine the influence of polyester fiber on the performance of asphalt mixes. Two types of polyester fiber were selected: one is locally made and the other is imported. El-Hamarawy et al. [16] made a study to investigate the effect of adding short fibers on the mechanical properties of asphalt concrete mixes. In this research, Marshall test, indirect tensile strength and static creep test were performed on both control and fiber mixes to evaluate their performance, and the test results indicated that addition of wool, linen and fibrin fibers had exhibited an improvement of the mechanical properties of asphalt concrete mixes. El-Batal [17] studied the effect of adding two different types of polymers (HDPE, SBR) to various asphalt contents to improve the properties of asphalt mixes, especially rutting resistance. The study indicated that the addition of HDPE or SBR to asphalt cement had improved the workability of mixes by improving the mechanical properties of the aged asphalt. Naglaa [18] made a study to investigate the effect of adding PET in different concentration (11, 12, 13, 14 and 15%) of the weight of asphalt on the mechanical properties of asphalt concrete mixes. Evaluation of the performance was based on Marshall, indirect tensile strength, rutting test and bending test. These data were confirmed by the BISAR computer program.

The objective of this study was to evaluate the effect of the resin modifiers material on the properties of hot mix asphalts. These resins were: unsaturated polyester resin (UPR), epoxy resin (ER) and unsaturated polyester resin mixed with 3% epoxy resin (UPRER). Marshall test was conducted to study these properties for controlled hot asphalt mixtures and resin - modified mixtures at various resin contents. Also, a computer program named BISAR was used to determine the total stress, strain and displacement in x-y, and z-direction of pavement that were flexibly constructed with these hot mix asphalts modified with resin additives.

2. Materials used

The crushed limestone was used as a coarse aggregate, siliceous sand as a fine aggregate and limestone dust as mineral filler. The aggregate gradation was selected according to one of the comments used gradation of the Egyptian code 1998 (Dense gradation 4C). The gradation of the combined aggregate along with the specification limit is presented in Fig.1. The nominal maximum aggregate size was 25mm. The bulk specific gravities of coarse aggregate, fine aggregate and mineral filler used were 2.655, 2.658 and 2.75

respectively. The average bulk specific gravity for aggregate was 2.688. The Los Angeles abrasion and absorption percent of coarse aggregate were 28% and 1.6% respectively.

The asphalt cement used was AC 60/70. This asphalt material, supplied by El-Suez is the usual asphalt grade used for asphalt pavement construction in Egypt. The properties of asphalt cement used are shown in Table 1.

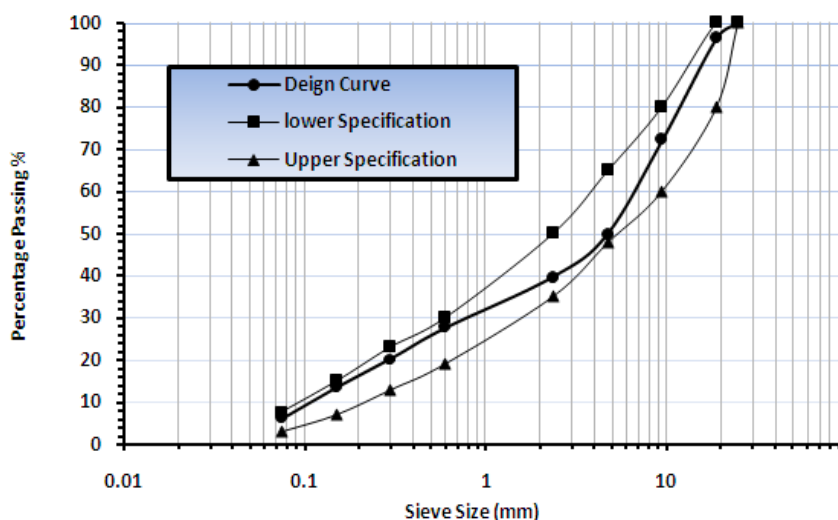


Fig.1. Grain size distribution of Aggregate used.

Table 1.

properties of asphalt cement.

Tests	value	Specification
Penetration (0.1 mm at 25 °C, 100 g, 5 s)	60	60/70
Kinematic viscosity (CSK)	335	+ 320
Softening point (c°)	50	45/55
Fire point (c°)	270	+ 250
Ductility (at 25 °C)	65	50 - 100
Specific gravity	1.02	1.02 – 1.05

Three types of resin additives including unsaturated polyester resin (UPR), epoxy resins (ER) and unsaturated polyester resins mixed with 3% epoxy resin (UPRER) were selected as modifiers to prepare asphalt mixtures. The properties of the unsaturated polyester resin (UPR) and epoxy resins are shown in Table 2. The contents of unsaturated polyester resin, epoxy resin and unsaturated polyester resin mixed with 3% epoxy resin in asphalt mixtures are 1%, 2%, 3%, 4% and 5% of the weight of asphalt were used at O.A.C.

Table 2.
selected properties of UPR and ER modifier

Properties	Types of modifier	
	UPR	ER
S.G. (25 C°)	1.138	0.98
Viscosity (Ps)	3.00	2.25
Acid Value	20.0	-
Styrene Content (%)	40	-
PH	-	10.5
Total Solid (%)	-	50
Appearance	Clear liquid	Milky-white liquid

3. Experimental work

The coarse aggregate, fine aggregate, mineral filler and asphalt cement were used to prepare the Marshal Test specimens with 65 mm height and 101.6 mm diameter. The tested asphaltic concrete mixes were composed of 60% coarse aggregate, 36% fine aggregate, 4% mineral filler and asphalt cement. For control mix, five different asphalt contents (4, 4.5, 5, 6 and 7%) were used to prepare Marshal Test specimens. The results of Marshal Design indicated that the optimum asphalt content for control mixtures was 5.3 %.

Resin modifiers were added separately in different concentration to asphalt cement and mixed for one minute. After mixing hot aggregate with asphalt cement with resin modifier, samples were compacted using Marshall Hammer with 50 blows /side to represent medium traffic volume. Marshal test was conducted on both control and resin modifiers mixes to evaluate their performance.

4. Experimental test results

4.1. Effect of resin modifiers on marshal stability

Figure 2 shows the test results of stability of all types of resin modifiers. The results had clearly shown that the epoxy resin (ER) gave higher values of stability than the unsaturated polyester resin (UPR). The reason for using unsaturated polyester resin mixed with 3% epoxy resin (UPRER) was that the high stability value occurred at 3% epoxy resin content. The hot mix asphalt samples together with UPRER gave the highest stability, followed by ER and UPR. It reveals that the stability increases with the increase of UPRER up to 3%, and then they decrease. Unlike, the stability decreases with the increase of both types UPR and ER content up to 1%, then they increase up to 3% and then they decrease again. It was noticed that stability of asphalt mixtures with type UPRER resin modifiers was always higher than the control mixture. Unlike, for type ER and UPR the stability was lower than the control mixture up to 1% and 2% respectively, then they increase. Generally, the uses of UPR, ER and UPRER improved the marshal stability, especially the later mix. The

reason may be, in this asphalt mixed with resin modifiers having a suitable consistency to cover all aggregate particles resulting in a strong bond between aggregate particles and leads to increase stability values.

Figure 3 shows the percentage of increase in stability due to adding resin modifier to hot mix asphalts at 3% resin content compared with control mix. Marshal stability increased by 4.76%, 9.63% and 16.17% for mixtures containing UPR,ER and UPRER respectively.

4.2. Effect of resin modifiers on marshal flow

Figure 4 shows the test results of flow for all modified types. It reveals that the flow increases with the increase of resin modifiers content up to 2% with all types of resins, then it decreases. It is clear from the results that the unsaturated polyester resin mixed with 3% epoxy resin (UPRER) gave the highest values of flow, than the unsaturated polyester resin (UPR) and epoxy resin (ER) respectively.

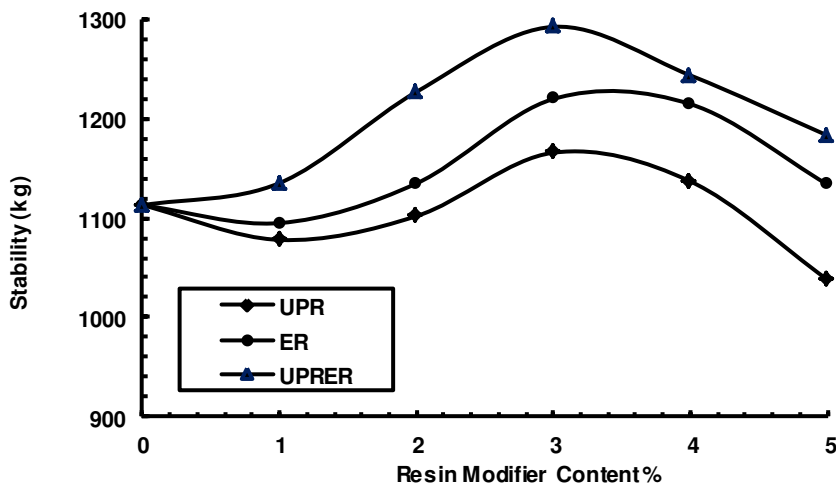


Fig. 2. Marshal Stability Versus Resin Modifiers Content

4.3. Effect of resin modifiers on bulk density

The relationships between resin modifiers content and bulk density are illustrated in Fig.5. It was noticed that the bulk density values increased by increasing resin modifiers content for all types of resins modifiers up to 2%, then they decreased. It was also noted that the highest bulk density for mixtures containing resins was obtained for mixes with the unsaturated polyester resin (UPR). The types with epoxy resin (ER) and unsaturated

polyester resin mixed with 3% epoxy resin (UPRER) gave the lowest values of bulk density respectively.

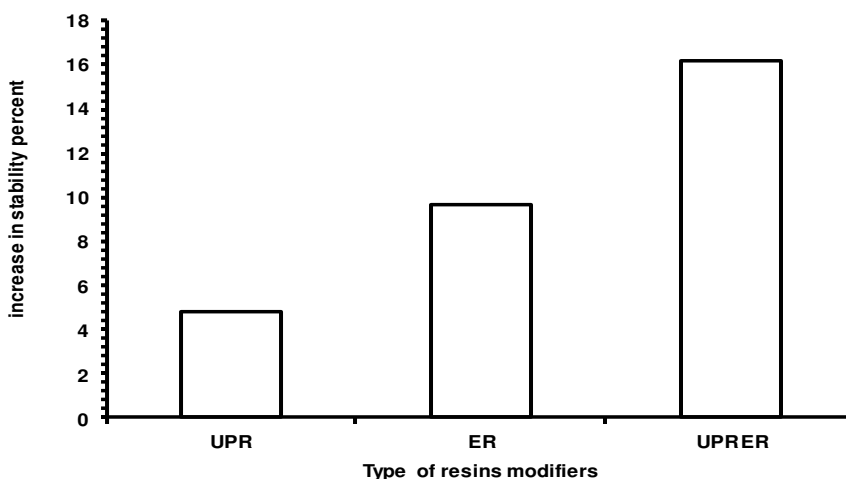


Fig. 3. Percent Increase In Marshal Stability at 3% Resin Content Compared With Control Mix.

4.4. Effect of resin modifiers on air voids

Figure 6 shows air voids versus resins modifiers content for all types of resins. It reveals that the air voids decrease with the increase of resins content for all types of resin modifiers up to 2%, then they increase. This result may come up because the resin modifiers fill some of the voids of asphalt concrete samples. The hot mix asphalt samples together with the unsaturated polyester resin mixed with 3% epoxy resin (UPRER) gave the highest values of air voids, than the epoxy resin (ER) and unsaturated polyester resin (UPR) respectively.

4.5. Effect of resin modifiers on VMA

The relationships between resins modifiers content and Voids in Mineral Aggregate (VMA) are illustrated in Figure 7. It reveals that the (VMA) values decrease with the increase of resin modifiers content for all types of resins up to 2%, then they increase. This result may be shown because the resin modifiers fill some of the voids of mineral aggregate in asphalt concrete samples. The mixtures samples together with UPRER gave the highest values of VMA, than the ER and UPR respectively.

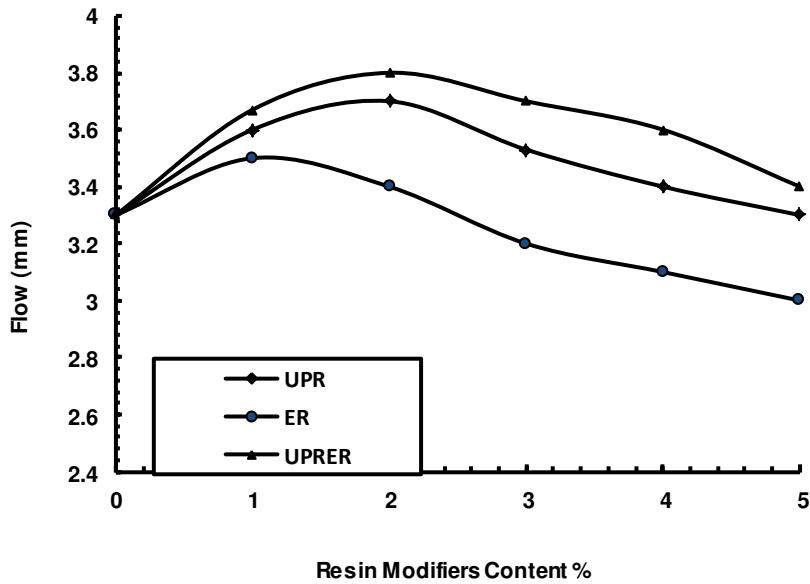


Fig. 4. Marshal Flow Versus Resin Modifiers Content.

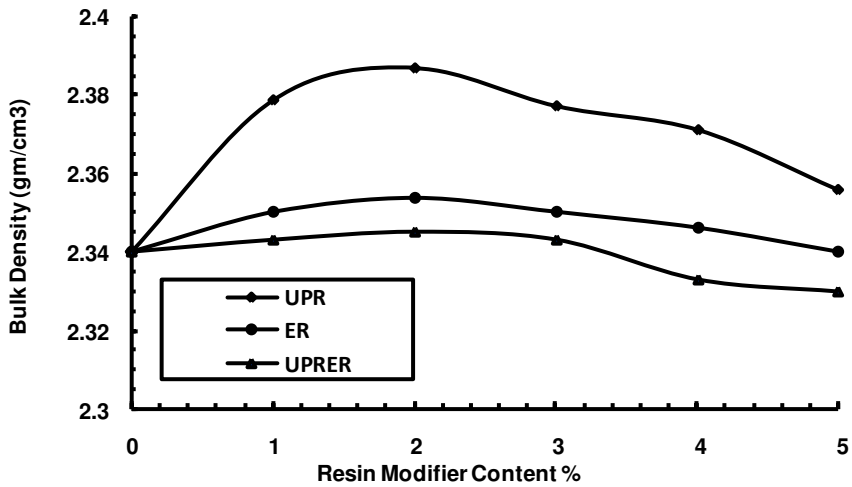


Fig. 5. Bulk Density Versus Resin Modifiers Content.

4.6. Effect of resin modifiers on VFA content

Figure 8 shows voids filled with bitumen (VFA) versus resin modifiers content for all types of resins. It reveals that the (VFA) increase with the increase of resin modifiers content for all types of resins up to 2%, and then they decrease. The mixtures samples together with UPR gave the highest values of VFA, than the ER and UPRER respectively.

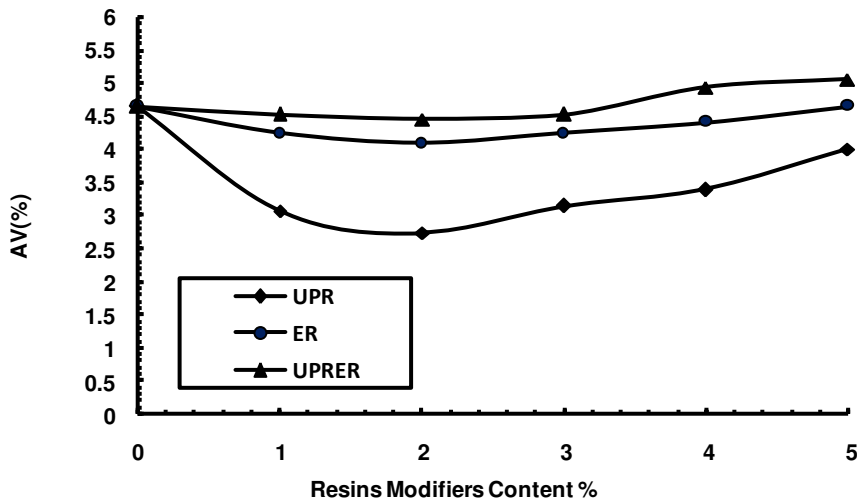


Fig. 6. Air Voids Versus Resin Modifiers Content.

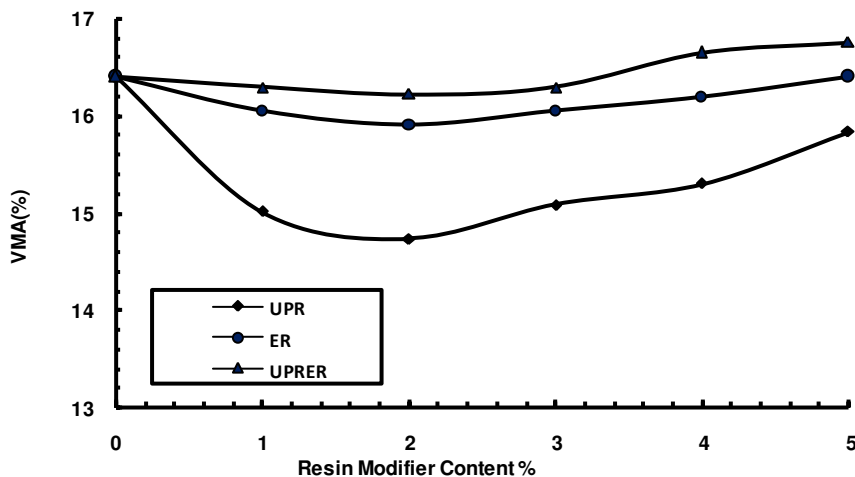


Fig. 7. VMA Content Versus Resin Modifiers Content.

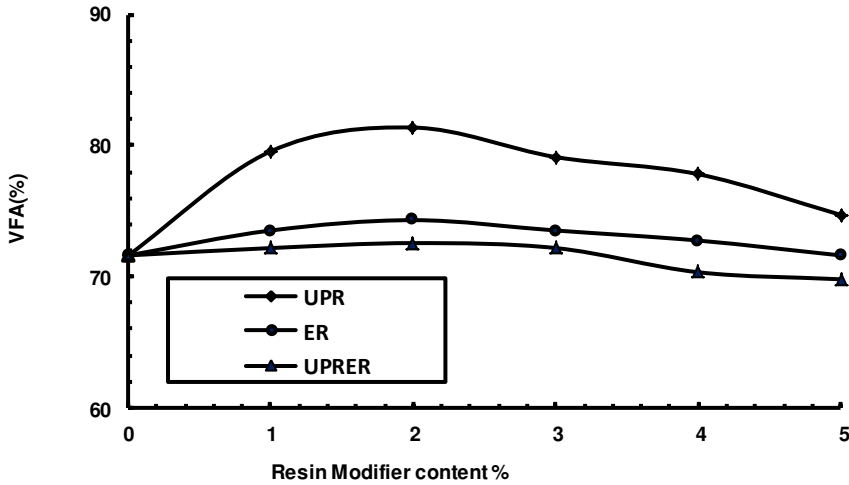


Fig. 8. VFA Content Versus Resin Modifiers Content.

5. Numerical analysis of flexible pavement modified with resins using bisar

5.1. General

Using both experimental work results of hot mix asphalt samples at 3 % percent of additive resins for different types of resins and a computer program named BISAR, the total stress, strain and displacement in x-y, and z-direction of flexible pavement constructed with hot mix asphalt mixed with resin additives were calculated.

The response model, BISAR 3.0, is a Windows version of linear elastic multi-layer program. BISAR is able to calculate stresses, strains and displacements at all points of a multi-layer pavement structure.

However, like most multi-layer models, BISAR also use several simplifications which are summarized as follows:

1. The pavement structure exists of at maximum 10 layers whereby the last layer describes the sub-grade as a semi - infinite half space.
2. All layers have infinite width and length.
3. Materials of the different layers are considered to be homogeneous, isotropic and elastic. Stress and strain distribution is linear according to the theory of elasticity (Hooke)
4. Self weight of the layers is discounted
5. Load is distributed over a circular area with constant contact pressure.

For the procedure of design and analysis of pavement structures using BISAR, the following input data are required:

1. Number of layers.
2. Thickness of the layers.
3. Modulus of elasticity (E) and the Poisson's ratio (ν) of the layers.
4. An interface shear spring compliance at each interface to study the effect of full or partial slip among the layers.
5. Number of loads with the co-ordinates of the position of the center of the loads.
6. A combination of two of the following three components to indicate the load: stress, load and radius [19].

The modulus of resilience M_r for different use mixes was determined using stability obtained from experimental results of asphalt concrete mix samples according to the Egyptian Code part 5. Using AASHTO method, the thickness of various types of layers of flexible pavement was determined using parameters shown in Table (3).

Table 3.
different parameters used in AASHTO design

Type	Stability (Ib)	M_r (psi)	a_1	a_2	a_3	SN_1	SN_2	SN_3
UPR	2500	520×10^3	0.495	0.14	0.11	2.4	2.64	4.46
ER	2700	570×10^3	0.525	0.14	0.11	2.4	2.64	4.46
UPRER	2925	625×10^3	0.555	0.14	0.11	2.4	2.64	4.46

For analyzing the pavement structure, we have chosen the layers thicknesses in the pavement model because they are close to those of the existing pavement. The pavement structure selected for this study obtained from AASHTO design method consists of 100, 120, 140 mm thickness of asphalt surface layer modified with UPR, ER and UPRER respectively, a 300 mm thickness granular crushed limestone layer as a base course, a 150 mm thickness granular crushed limestone layer as a subbase and a subgrade (silty soil) at the bottom. The configuration for structure used in the analysis is illustrated in Figure 9. The material characteristics used in the analysis are considered to be representative of the variety in the selected pavement structures. They are summarized in Table (4).

The data shown in Table (4) are fed to the BISAR computer program to obtain the total stress, strain and displacement due to loading on the surface of pavement.

5.2. Pavement analysis results and discussion

The contact forces distribution inside the pavement and its behavior has been monitored. Figure 10 shows how the contact forces induced by loading process are distributed inside the pavement. They develop at the contact patches, spread in the asphalt layers and then in the sub-base course. They have a radial distribution around each contact patch and their intensity is mostly compressive.

Table 4.

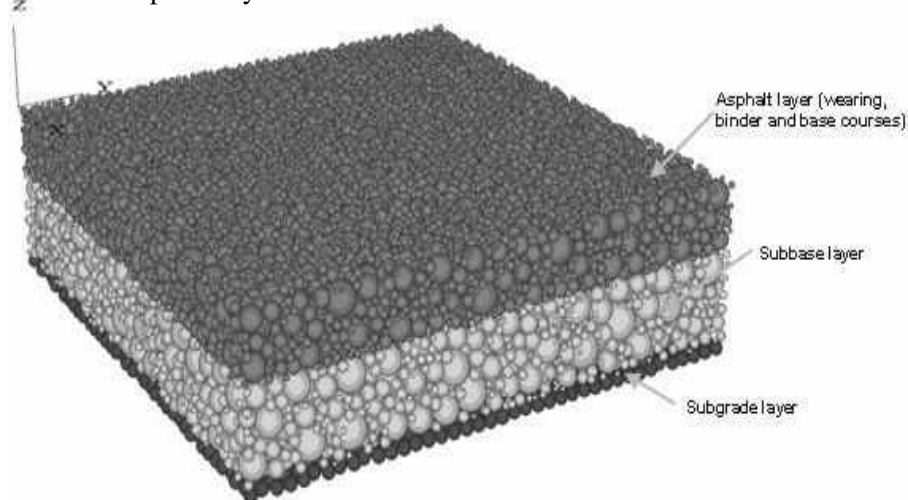
Layer thickness and elastic material properties used in the analysis

Layer No.	Material	Resin type	Thickness (mm)	Modulus of Elasticity (E) kg/cm ²	Poisson's ratio (ν)
1	Surface layer	UPRER	100	3600	0.35
		ER	120	3500	0.35
		UPR	140	3400	0.35
2	Base		300	500	0.37
3	Subbase		150	150	0.45
4	Subgrade		infinite	50	0.49

The effect of pavement depth on deflection, stress and strain was determined. The responses obtained at planes of symmetry and through C.L. of wheel at surface and layers interface and subgrade are analyzed and described in the following section. Figure 11 below shows the locations at which deflection, stress and strain were determined, analyzed and described.

5.2.1. Effect of resin modifiers on total stress

Figures 12 and 13 show the total stress versus the depth under the pavement surface for pavement modified with all types of resins at 3% content in the direction of xx, yy and zz. It is noticed that the total stress increases as the depth increases to 10 cm, then by increasing depth than 10 cm it decrease still it reaches approximately a zero value. The maximum total stresses in case of UPRER have the highest values, then those achieved by ER and UPR respectively. That is the modulus of resilience of UPRER is higher than that of ER and UPR respectively.

**Fig.9.**Pavement configuration used in analysis.

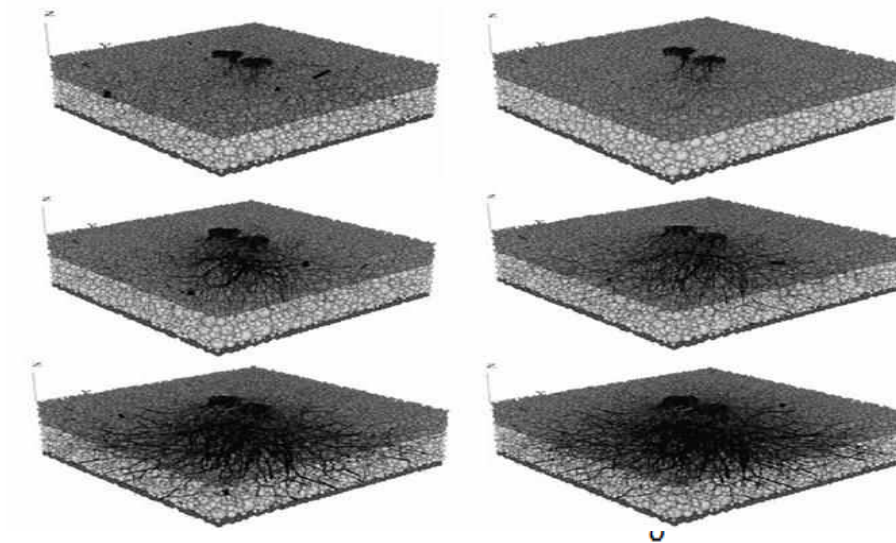


Fig. 10. Contact forces distribution inside the specimen during the loading.

Locations

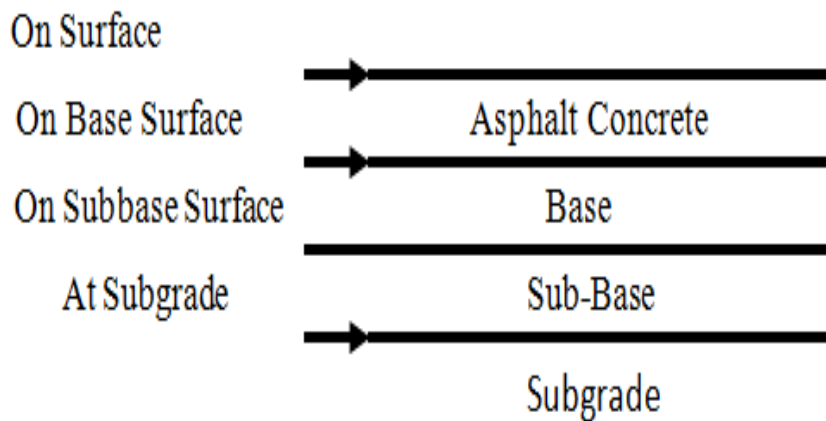


Fig. 11. Pavement surface location at which deflection, stress and strain were determined

5.2.2. Effect of resins modifiers on total strain

The relationship between total strain of different resins and the depth under pavement surface in the direction of xx, yy are shown in Figures 14. It is noticed from this figure that the total strain increases with the increase of depth till 10 cm, then by increasing depth than 10 cm it decreases. The maximum total strain in case of UPRER has the highest values, then the ones achieved by ER and UPR respectively.

Figure 15 shows the relationship between the total strain and the depth under pavement surface in the direction of zz for all types of resins modifier. It is noticed from this figure that the total strain for UPRER increases with the increase of depth till 10 cm, then it decreases. Unlike, for types ER and UPR the total strain decreases with the increase of depth till 10 cm, then by increasing depth than 10 cm it increases.

5.2.3. Effect of resin modifiers on total displacement

Figure 16 shows the total displacement versus the depth under the pavement surface for pavements modified with all types of resins in the direction of zz. It is noticed that the total displacement decreases with the increase of depth. The total displacement in case of UPRER has higher values than that achieved by ER and UPR respectively.

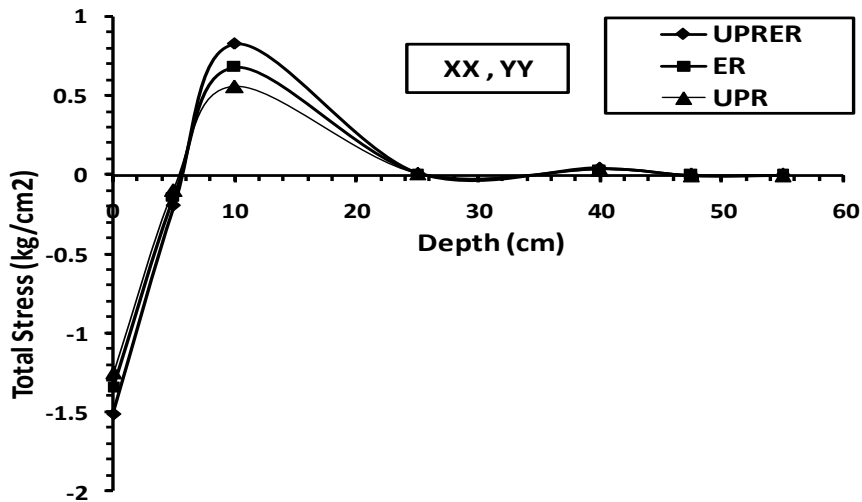


Fig. 12. Total stress versus depth under pavement surface at direction xx and yy for all types of resins modifiers.

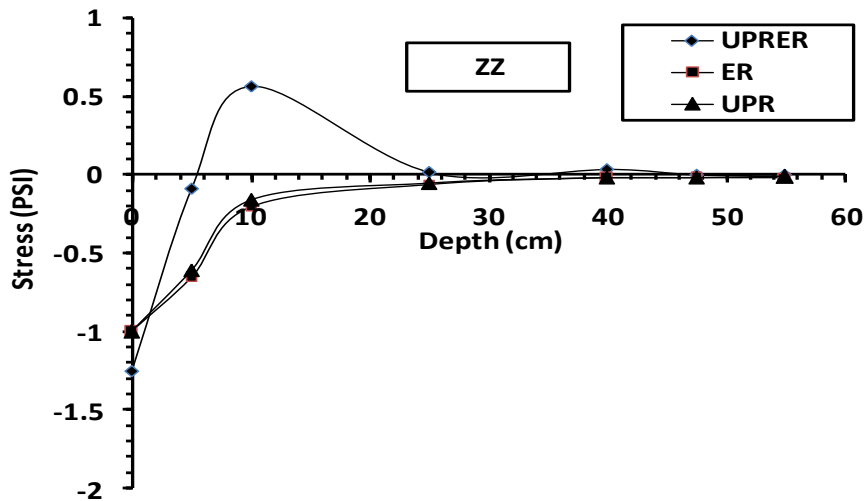


Fig. 13. Total stress versus depth under pavement surface at direction zz for all types of resin modifiers.

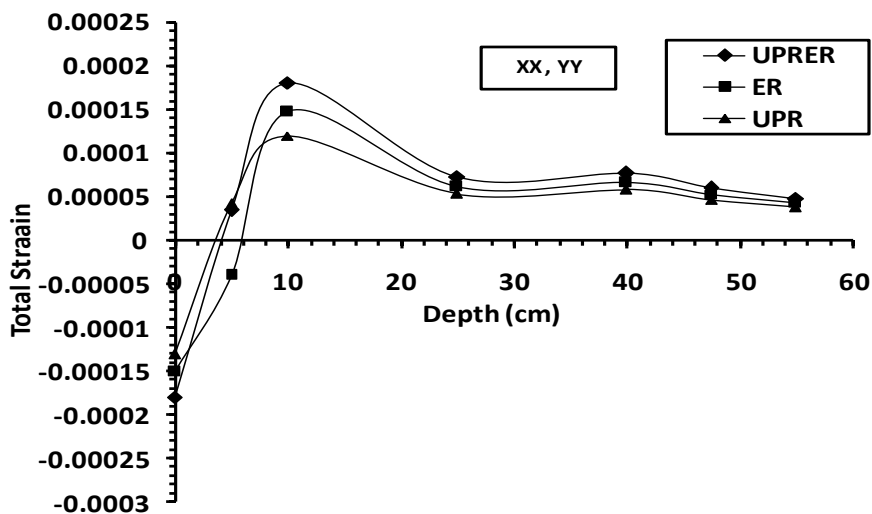


Fig. 14. Total strain versus depth under pavement surface at direction xx and yy for all types of resins modifier.

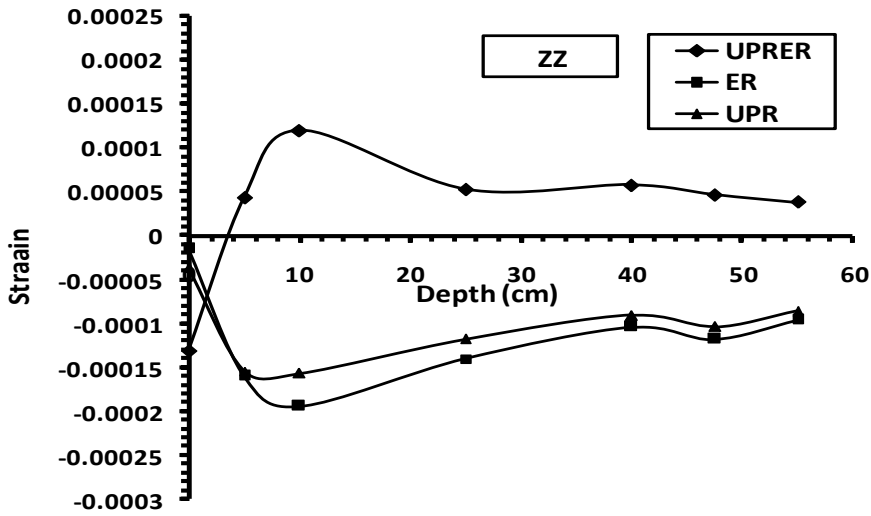


Fig. 15.Total strain versus depth under pavement surface at direction zz for all types of resin modifiers.

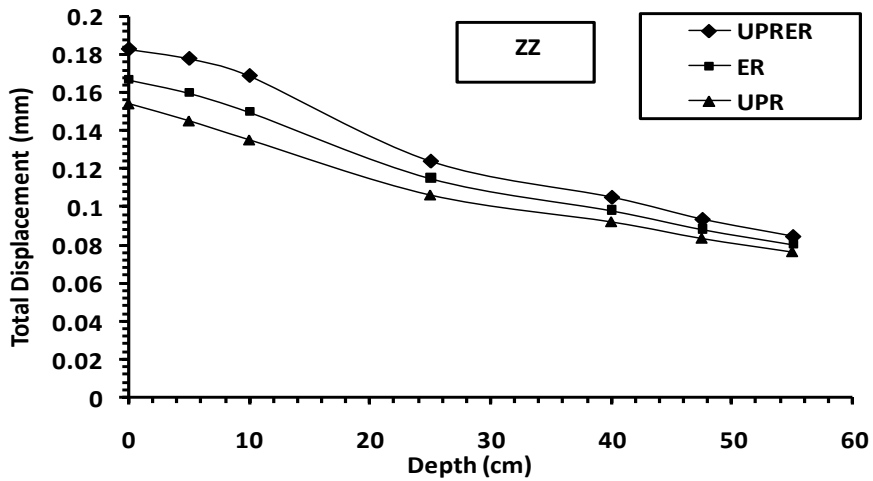


Fig. 16.Total displacement versus depth under pavement surface at direction for all types of resins.

6. Conclusions

Based upon the analysis of the experimental investigation and numerical analysis of flexible pavement using BISAR program presented in this study, the following conclusions are drawn:

1. Marshal stability for mixes with resin additives (polyester, epoxy and polyester mixed with 3% epoxy) has improved compared with the conventional mixtures.
2. Maximum Stability values were achieved at 3% resin content of the weight of asphalt cement for all types of resins.
3. At 3% resin content, Marshal stability increased by 4.76%, 9.63% and 16.17% for mixtures containing UPR, ER and UPRER respectively.
4. Marshal Stability of mixtures using UPRER was higher than UPR and ER.
5. Bulk density values increased by increasing resin content up to 2% for all types of resins, then they decrease. Also, UPR gave the highest values of bulk density followed by ER and by UPRER.
6. The addition of about 2% resins to the weight of asphalt cement for all different resins gave a higher value of flow when compared with the other percentages of resins. Also, the flow values of asphalt concrete mixtures with ER were lower than those of mixtures containing UPR and UPRER respectively.
7. Both the Air voids (AV) and the Voids in Mineral Aggregate (VMA) decreased by increasing resin content up to 2% for all types of resins, then they increased. The UPR gave the lowest values.
8. The voids filled with bitumen (VFA) percent increased with the increase of resin additive content for all types of resins up to 2%, then they decreased.
9. Both the total stress and strain increase with the increase of depth till 10 cm, then by increasing depth than 10 cm it decreased for all types of resin modifiers. The maximum total stresses and strain in case of UPRER have higher values than those achieved by ER and UPR respectively.
10. The total displacement decreased with the increase of depth. In the case of UPRER the total displacement has higher values than that achieved by ER and UPR respectively.

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Symbols and abbreviations

HMA	Hot Mix Asphalt
UPR	Unsaturated Polyester Resin
ER	Epoxy Resin
UPRER	Unsaturated Polyester Resin mixed with 3% Epoxy Resin
AV	Air Voids
VMA	Voids in Mineral Aggregate
VFA	Voids Filled with Bitumen
E	Modulus of Elasticity
v	Poisson's ratio
M _r	Modulus of Resilience

a ₁	Surface Layer Coefficient
a ₂	Base Course Layer Coefficient
a ₃	Subbase Layer Coefficient
SN ₁	Structure Number for Surface Layer
SN ₂	Structure Number for Base Course Layer
SN ₃	Structure Number for Subbase Layer

ملخص:

من أجل دراسة تأثير اضافة المواد الراتنجية على أداء الخلطات الإسفلتية الساخنة تم اختيار نوعين منالمواد الراتنجية للدراسة أحدهما هو راتنجات البوليستر غير المشبع (UPR) والآخر هو راتنجات الايبوكسي (ER). كما تم ايضا استخدام راتنجات البوليستر غير المشبعة مختلطة بنسبة 3٪ من راتنجات الايبوكسي (UPRER) وذلك بناء على نتائج الاختبارات التي اعطت افضلية لنسبة 3٪ اضافات. وأجرى اختبار مارشال للدراسة كل من الثبات، والانسياب، والكثافة الطبيعية، ونسبة فراغات الهواء (AV)، ونسبة الفراغات في الركام المعدني (VMA)، ونسبة الفراغات المملوءة بالبيثومين (VFA) لكل من الخلطات الإسفلتية الساخنة بدون اضافات والخلطات الإسفلتية الساخنة مع وجود اضافات من المواد الراتنجية بنسب اضافات مختلفة.

كما تم استخدام برنامج كمبيوتر يسمى BISAR لتحديد كل من الاجهاد والانفعال الكلى والحركة الافقية فى كل من الاتجاهات الثلاثة السينى والصادى والعينى للطرق المرصوفة رصف مرن باستخدام هذه الخلطات الإسفلتية الساخنة المضاف لها الراتنجات.

وقد أظهرتا لنتائج التجريبية أن جميع الخلطات الإسفلتية الساخنة المضاف لها هذه الراتنجات اعطت زيادة ملحوظة فى الانسياب والكثافة الطبيعية، ونسبة الفراغات المملوءة بالبيثومين (VFA) مقارنة مع الخلطات التى تمت بدون اضافات. وان راتنجات البوليستر غير المشبعة المختلطة بنسبة 3٪ من راتنجات الايبوكسي (UPRER) اعطت دائما ثبات اعلى من الخلطات التى تمت بدون اضافات. على عكس ذلك فان الانواع ER، UPR اعطت قيم اقل للثبات من الخلطات التى تمت بدون اضافات حتى محتوى اضافات 1%، 2% على التوالى ثم بعد ذلك يزداد الثبات. وقد لوحظ ايضا ان الخلطات المضاف لها UPRER اعطت أعلى قيم لكل منالثبات والانسياب، ونسبة فراغات الهواء (AV)، ونسبة الفراغات فى الركام المعدني (VMA) منأنواع الراتنجات الاخرى المستخدمة فى الخلطات. وعلاوة على ذلك، أعطى راتنجات البوليستر غير المشبعة (UPR) أعلى قيمة للكثافة الطبيعية ونسبة الفراغات المملوءة بالإسفلت (VFA). وقد لوحظ ايضا ان اقصى قيمة للثبات حدثت عند استخدام اضافات بنسبة خلط 3٪ لكل انواع الراتنجات.

وتم استنتاج ان الاجهاد والانفعال الكلى يزداد نسبيا مع زيادة عمق الرصف حتى عمق 10 سم ثم بعد ذلك ينخفض لجميع أنواع الخلطات المضاف لها الراتنجات. والخلطات المضاف لها راتنجات البوليستر غير المشبعة مختلطة مع نسبة 3٪ راتنجات الايبوكسي UPRER اعطت أعلى قيم لكل من الاجهاد الكلى والانفعال الكلى بالمقارنة بالقيمتى حققتهما كل من الخلطات المضاف لها ER، UPR على التوالى. ووجد ان الحركة الافقية تتناقص مع زيادة عمق الرصف وان الخلطات المضاف لها UPRER اعطت أعلى قيم للحركة الافقية بالمقارنة بالقيمتى حققتهما كل من الخلطات المضاف لها ER، UPR على التوالى. ولأن اضافة الراتنجات للخلطات الإسفلتية تحسن من اداء الخلطات الإسفلتية لذا فانها ستكون ذات فائدة كبيرة لمجال هندسة الطرق.