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PRODUCTION OF HIGH MODULUS ASPHALT CONCRETE WITH HIGH RUTTING RESISTANCE

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ABSTRACT

The conventional Hot Mix Asphalt (HMA) may suffer from several distresses such as fatigue cracking and rutting. The High Modulus Asphalt Concrete (HMAC) designed according to French method (Enrobés À Module Élevé - EME) can be considered as one of the important solutions for these distresses. The current research involved using the obtained hard grade bitumen from previous research by authors with good quality and specific gradation of aggregate to produce HMAC according to EME2 mix design method. The mix design procedure and the performance tests of EME2 method were adopted as much as possible according to the corresponding standards of EME; however, some alternative test techniques were adopted due to the unavailability of instruments. According to gained results of HMAC, the workability of HMAC showed satisfactory results, and the moisture sensitivity resistance of HMAC was higher than the conventional mixture by about 24%. The rut depth test results at 60°C showed that the rut depth of HMAC was 5.3 mm (as an average value for these specimens) at 10,000 cycles, while, the control mixture was tolerate a rut depth of 20 mm at 7500 cycles. The HMAC stiffness modulus value was more than conventional mixture by about 3.6 times. Based on the stiffness modulus test results, two programs of KENLAYER and FAARFEILD software were used to predict the fatigue life and reduction in pavement thickness for HMAC and conventional mixtures respectively. The results of estimated fatigue life showed that the HMAC mixture can carry about 7.2 times of axle-load applications more than conventional mixture before exhibited fatigue cracks. Regarding to reduction in pavement thickness, the HMAC showed about 33% reduction in thickness of asphaltic concrete layer. Consequently, the using of the obtained mixture is significantly reduced the construction cost of pavement roads in addition to the great improvement in mechanical behaviour of the obtained HMAC compared with conventional mixtures.

Keywords: hard grade bitumen, high modulus asphalt concrete, enrobés À module elevé (EME), crumb rubber.

INTRODUCTION

The conventional Hot Mix Asphalt (HMA) may be subjected to different modes of failures such as (fatigue and permanent deformation) due to temperature changes and loading stresses through its design life [1, 2]. High modulus asphalt concrete (HMAC) mixture design method known as (EME) was applied in France as one of the proposed solutions to decrease occurrence of pavement failure especially due to rutting by introducing mixture with hard grade bitumen, higher binder content, high stiffness and lower porosity (3-5%) compared to the traditional mixture [3]. HMAC has been adopted by many countries such as United Kingdom; Poland, Switzerland, South Africa and Australia [4, 5].

In order to obtain HMAC according to EME method, a hard grade bitumen of penetration grade (10-20) or (15-25) with high content (approximately 6%) is required [4]. This Mixture (HMAC design according to EME) is characterised as a high stiffness modulus, high moisture damage resistance, superior resistance to rutting, and good resistance to fatigue [6]. HMAC was usually designed to be used in base or binder courses of heavy-duty pavement especially for thickness reduction purposes [7]. HMAC can be considered as a cost-effective solution in roads construction by saving in materials compared to conventional asphalt pavement. However, the using of HMAC with high stiffness may raise some concerns relating to fatigue cracking especially in cold climatic conditions. These concerns may be relieved by improving the elastic recovery (flexibility) of the hard grade bitumen using some modifiers, which improve mixture performance by increasing fatigue cracking resistance comparing to conventional hard grade bitumen [8].

EME mix design is classified as a performance evaluation based method focuses more on the performance tests characteristics than the volumetric properties of mixture adopted in most of the conventional methods of asphaltic mixture design [9]. The rutting, fatigue cracking and moisture damage resistance are the most important performance testes required in EME method. French standards identified two main classes of EME comprising: EME class 1 (EME1) and EME class 2 (EME2), the difference between them is the binder content which is controlled by a key design coefficient (Richness Modulus) [10]. It considered as an equivalent to bitumen film thickness coating the aggregate surface and can be computed depending on the density of combined aggregate (coarse, fine, filler), the proportions of aggregate particles on some specific sieves and percent of bitumen binder [11].

The workability of HMAC mixture is another requirement need to be checked according to EME method. Several techniques were proposed to evaluate the workability of the mixture based on percent of air voids after specific number of gyrations. In France, the gyratory compactor device of the French administration for the adopted applied research and developing of laboratory methods, LCPC (Labatoire Centrale tes Ponts et Chausees) was used, while, in Australia, servo-pack compactor was used [11]. Other study conducted by Denneman *et al.* [5] showed that the American Superpave Gyratory Compactor (SGC) device was also used for workability evaluation. Although, the most common method for specimens preparation and compaction is the gyration method using several types of gyratory compactors, the Marshall method of specimens preparation was also used in implementing of EME in several countries such as Latvia, Poland, and Switzerland in accordance with EN 12697-30 [4].

Several studies have been conducted to investigate the effect of hard grade bitumen and HMAC in enhancement of pavement performance. Some of these studies showed that the rutting resistance of HMAC is higher than that of the SBS modified asphalt mixture. Also, it showed that HMAC contributed to reduce the thickness of the base course by about quarter to one third of the thickness compared with the conventional mixtures [12]. Carbonneau *et al.* [13] carried out a direct tension test (EN 12697-26 annex E) to measure stiffness of cylindrical specimens of conventional mix for road base namely Graded Aggregate Base (GABII) containing bitumen (40-60) and high modulus GABII containing bitumen (20-30). The obtained result showed that stiffness modulus values of high modulus and conventional mixtures were 12100 Mpa and 6260 Mpa respectively.

The fatigue resistance and moisture sensitivity resistance of HMAC are related more to binder content; in which, the increase in binder content produce more fatigue life and damage resistance [14, 15]. The using of CR as an additive in production of HMAC could improve the fatigue resistance and increase the fatigue life of HMAC pavement [8] While, the stiffness and rutting resistance of HMAC are related to the properties of binder (hardness), and aggregate type [14]. Espersson [16] observed that the HMAC containing HMAB (13-22) has high dynamic modulus reached up to 50 % more than dynamic modulus of conventional mixtures manufactured with (40-50) or (60-70) at different temperature (20, 10, 0, -10, and -20 °C). Haritonovs *et al* [3] evaluated the permanent deformation resistance and stiffness modulus of reference mixture having conventional bitumen (70/100) and two types of HMAC with different binder content comprising of Polymer Modified Bitumen (PMB) (10/45-65) and hard grade bitumen (20-30). Their results showed that HMAC with lower content of PMB has highest rut resistance. Also, it was cleared that the HMAC with hard grade binder showed higher stiffness modulus than that of HMAC with PMB. Judycki *et al.* [17] carried out a field investigation related to the stiffness modulus and low-temperature cracking resistance on conventional and HMAC pavement for selected roads located in Poland. The results of FWD (Falling Weight Deflectometer) test showed that the deflection of HMAC pavement is lower than that of conventional pavement and the stiffness of HMAC is higher than conventional pavement by two times. Several studies showed that the using of alternative methods of testing for that proposed by EME may affect the obtained results [4].

This research aims to produce HMAC by using the hard grade bitumen modified with CR produced by authors [18] , which was confirmed to the requirement of hard grade bitumen (mentioned in BS EN 13924-1). The aggregate type and gradation were adopted according to [19]. The performance testes of EME method were followed as can as possible for HMAC to meet EME2 requirement according to the equipment availability. These tests involved the moisture sensitivity, stiffness modulus and wheel tracking tests. Fatigue resistance is another performance test recommended as a requirement for EME method, however, an indirect estimation of the fatigue life was proposed by using the asphalt institute model based on the measured elastic modulus with the aid of supported software program (KEN-PAVE). The reduction in thickness for pavement section incorporating HMAC has been estimated with the aid of FAARFIELD and KENPAVE program.

MATERIALS AND METHODOLOGY

Materials

Conventional and hard paving grade bitumen

Conventional bitumen binder with penetration grade of (40-50) was used to produce hard paving grade bitumen [18] used for production HMAC. The properties of hard grade bitumen binder (with and without CR) are listed in Table-1. All tests for binder properties were conducted according to BS EN (British Standards - European Norm Standards) Standards as required for hard paving grade bitumen and EME2 method except the ductility of bitumen which was tested according to ASTM. The ductility test is not specified as a requirement for hard grade bitumen and EME2 method; however, it was conducted to give an indication about asphalt binder flexibility.

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Table-1. Specifications for hard paving grade bitumen [20] and the obtained physical properties of bitumen [18].

Property	Test method	Test result before CR addition	Test result after CR addition	Requirement (according to EME2)
Penetration,100gm,25°C, 5sec (1/10 mm)	EN 1426 [21]	17	18	(15-25)
Softening point (ºC)	EN 1427 [22]	61	61	(55-71)
Flash point, (ºC)	EN 2592 [23]	> 300	> 300	≥ 235
Solubility	EN 12592 [24]	99	98.16	≥ 99 before CR addition and ≥ 97 [25] after CR addition
Dynamic (Rotational) viscosity at 135 ºC (Pa sec.)	EN 13302 [26]	0.85	0.87	0.6
Kinematic viscosity at 135 ºC (mm2/sec.)	EN 12595 [27]	817	844	≥ 600
Ductility,25 ºC, 5 cm/min, (cm)	ASTM D 113-99 [28]	18	24	
Penetration index (IP)	EN 13924, Annex A	-0.977	-0.883	-1.5 ≤ IP ≤ + 0.7
After Thin film oven test EN 12607-1 (163°C, 50gm, 5 hr.)				
Softening point (ºC)	EN 12607–1+ EN 1427	63	65	≥ orig. min. + 2 °C
Retained penetration of original (%)	EN 12607–1+ EN 1426	63	63	≥ 55
Increase in softening point(°C)	EN 12607–1+ EN 1427	2	4	≤8
Mass loss (%)	EN 12607–1 [29]	0.09	0.1	≤ 0.5

Aggregate

The aggregate used in this work were obtained from local sources (Badrah quarries). The aggregate were selected as high quality aggregate (in terms of quality, shape properties and derbies purity) to meet the French requirement for aggregate used in EME mix type. These requirements include using fully crushed (with no rounded particles) coarse aggregates and crushed sand with no natural sand (see Table-2, for the properties of the used aggregate). The selected aggregate gradation was adopted to meet both the requirement of EME2 [19] and superpave methods [30] as shown in Figure-1.

Mineral filler

Since EME mix required no hydrated lime or limited used in a mix, the Ordinary Portland Cement (OPC) is only type of filler used in this work [31].

Table-2. Physical properties of coarse and fine aggregate.

Property	Coarse aggregate		Fine aggregate	
	Result	Reference standards	Result	Reference standards
Bulk specific gravity, (gm/cm^3)	2.6	EN 1097-6 [32]	2.62	EN 1097-6
Apparent specific gravity, (gm/cm^3)	2.65	EN 1097-6	2.67	EN 1097-6
Water absorption, (%)	1.2	EN 1097-6	0.8	EN 1097-6
Los Angeles Coefficient (LA)	20	EN 1097- 2 [33]	-	-
Sand equivalent value of fine aggregate, (%)	-	-	64	EN 933- 8 [34]
Flakiness indexes	21	ASTM D4791 [35]	-	-
Percent of crushed surfaces in coarse aggregate particles, (%)	100	EN 933-5 [36]	-	-

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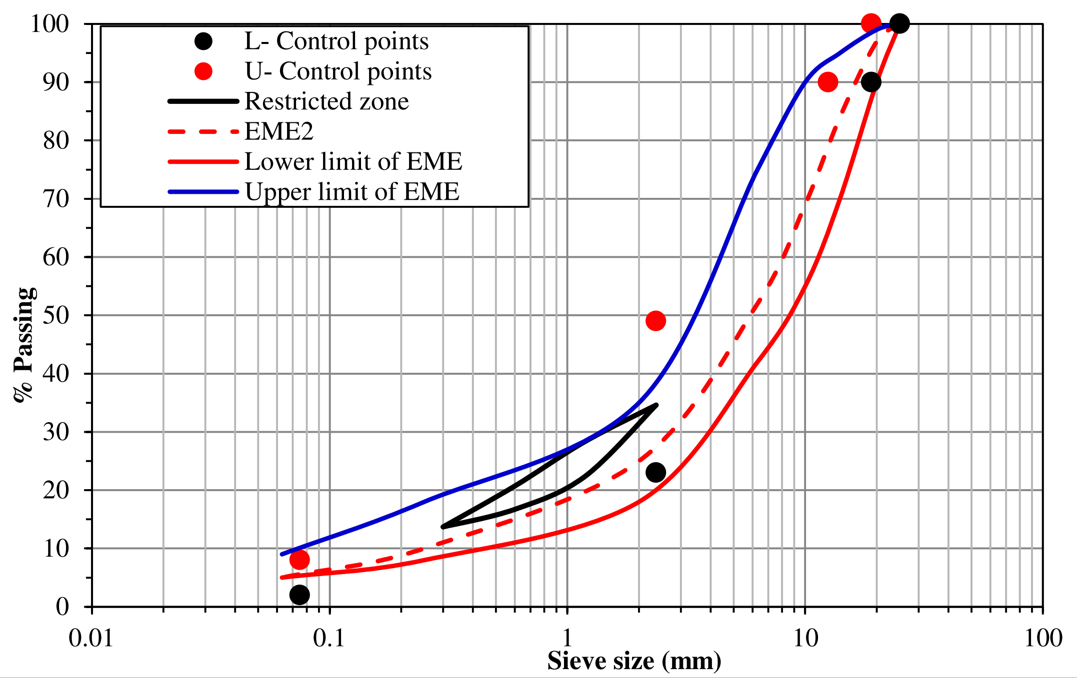

Figure-1. Particle size distribution of the selected gradation.

Experimental tests

Mix design procedure- Trail mixes

To produce HMAC, Marshall Method was used to prepare the specimens and select the Optimum Binder Content (OBC) for HMAC and conventional (control) HMA. This approach was adopted in literature for several studies [4, 37]. This method covers preparation of mixtures in accordance with [38], compaction of specimens using impact compactor in accordance with [39] and specimens testing using Marshall apparatus based on [40]. The calculated OBC for HMAC was compared with richness modulus (k) mentioned before. Richness modulus (k) is computed as a function of effective binder content, specific gravity of combined aggregate and the proportions of aggregate particles on some specific sieves [14]. The obtained OBC should be equal or greater than the minimum binder content calculated based on the minimum richness modulus value.

The workability of prepared HMAC should be evaluated and assured according to EME2 requirement before conducting the required performance tests. The evaluation process was conducted using SGC, in which the air voids were checked at the design number of gyration (N des) equal to 120 gyration based on EME2 requirement for mix type (AC 20 EME2) used in this research [4]. The selection of N des also match the required design number of gyration according to local conditions of temperature and traffic [41].

Mix design procedure-performance of trail mixes

Moisture sensitivity

Moisture sensitivity is one the performance tests required for EME method expressed by Tensile Strength Ratio (TSR) value. In this research the test was conduct by preparing specimens using optimum binder content for each mix type and conditioned according to EN 12697-12 as recommended by EME2. The procedure of the specimens testing was adopted as mentioned in corresponding standard [42].

Rut resistance

Rutting resistance is another performance test requirement in EME method. The third procedure with (small device procedure B testing in air) was used in the current study. The slab specimens with dimensions of (300*400*60 mm) were compacted under a load applied by a smooth steel roller according to (EN 12697-33) to simulate a binder layer. The test was conducted in air at a temperature of 60 ° C, the test has been continued until reaching 10,000 load cycles or rut depth of 20 mm as stated in EN 12697-22.

Stiffness modulus

The test was conducted using one of the suggested procedures in EN 12697-26 to calculate the stiffness modulus (indirect tensile test according to BS EN 12697-26 Annex C). Figure-2 shows the specimen in Universal Testing Machine device (UTM). Four specimens with optimum binder content have been prepared for each conventional mixture and HMAC mix without CR while; two specimens at OBC have been prepared for HMAC mix contained CR.

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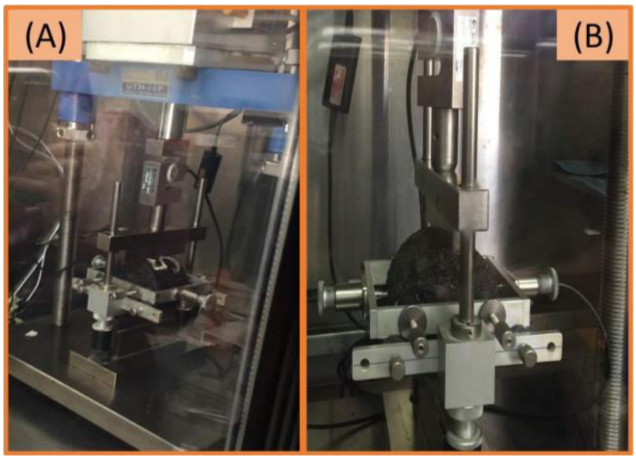

Figure-2. The specimen in UTM device.

Estimation of fatigue life and reduction in thickness

The fatigue life was estimated using an empirical formula. Although this approach may not very precise, but it may give an indication for the fatigue life of modified mixture (HMAC) compared to control (conventional) mixture using the measured value of the stiffness modulus. Two sections of pavement structure have been formulated in the KENPAVE program for conventional and HMAC mixture, each section consisted of three layers: asphaltic concrete layer, base layer and subgrade. The elastic modulus obtained from laboratory indirect tensile stiffness test was defined for each asphaltic concrete layer of conventional and HMAC pavement sections. While poisons' ratio and thickness for asphaltic concrete layer and other properties for underlaying layers (base and subgrade) were assumed to have the same properties for each pavement sections. All layers materials were assumed as linear elastic materials and subjected to the same loading condition (single load). The radial (tangential) tensile strain at the bottom of asphaltic concrete layer (as an output from KENPAVE) was used to predict the fatigue life.

To estimate the allowable number of load applications using Equation 1., the measured elastic modulus and the computed horizontal tensile strain at the bottom of asphaltic concrete layer were incorporated as shown in asphalt institute's fatigue equation below [43]:

$$N_f = 0.00432\, k1\, C\ (1/\varepsilon_t)^{3.9492}\, (1/\mathrm{E})^{1.287} \qquad (1)$$

N_f : Number of load repetitions to fatigue cracking failure

ε_t : Tensile strain at the bottom of asphalt surface layer

E : Elastic modulus of the asphalt layer

C = Function of percentage of binder content and air void

$$C = 10^M \qquad (2)$$

$$M = 4.84[\frac{V_b}{V_a+v_b} - 0.69] \qquad (3)$$

Where:

V_b : Percentage of binder content

V_a : Percentage of air void

$$\mathrm{K1} = \frac{1}{0.000398 + \frac{0.003602}{1+e^{(11.02-3.49\, H_{HMA})}}} \qquad (4)$$

K1 : Thickness correction factor

H_{HMA} : Total HMA thickness (in)

In order to determine the reduction in thickness, two approaches were adopted. The first approach involved the using of computer program, FAARFEILD 1.3 for structural design of two pavement sections involving HMAC mixture and conventional mixture. The two pavement sections were proposed composing of control section with asphaltic concrete layer of conventional mixture and modified section with asphaltic concrete layer of HMAC mixture. Each section consists of three layers (asphaltic concrete layer, base layer and subgrade), the same properties have been defined for each section expect for asphaltic concrete layer where the stiffness modulus was adopted as measured experimentally.

The second approach was depend on equal strains and displacements between two pavement sections of conventional and HMAC mixtures to determine the reduction in thickness of pavement structure.

RESULTS AND DISCUSSIONS

Mix Design Results

Marshall test results

The optimum value of binder content was determined as 4.9 % for control (conventional) mix samples (containing conventional bitumen) and 5.5% for modified samples (containing hard grade bitumen). Table-3, illustrates mixture properties at OBC for each type of mixture achieving the standard of (State Organisation of Roads and Bridges (SORB), 2003) in Iraq.

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Table-3. Properties of two mixtures at OBC and specification requirements.

Marshall property	Mixture type		Specification requirements of binder course [44]
	Conventional (40-50)	**HMAC (15-25)**	
Unit weight, (gm/cm^3)	2.342	2.357	-
Stability, kN	11.0	15.9	7 Min.
Flow, mm	3.6	3.6	2-4
Air Voids, %	3.8	3.1	3-5
VFA, %	77.16	81.05	-
VMA, %	13	15.86	13 Min

The obtained results of Marshall test revealed that the OBC and Marshall Stability value of modified specimens were more than the control specimens by 12% and 45% respectively. Therefore, it can be concluded that adding of these additives may increase binder stiffness due to their unique characteristics such as hardness, and consequently increase the value of Marshall Stability for HMAC mix specimens compared to control specimen. In addition, the high optimum binder content for HMAC mixture was observed ,this may be due to the increasing of viscosity of hard grade bitumen used in HMAC mix[18]. The increase of viscosity of bitumen means more bitumen binder is required to form a complete film of binder coating the aggregate particles.

Richness modulus determination results

From k, a minimum value of asphalt binder can be estimated to compare with obtained OBC. K value of 3.4 was used to calculate minimum binder content based on the quality and grading of the selected aggregate. The correction coefficient expressed as ($\propto$) was one of the parameters used to calculate richness modulus based on the specific gravity of the combined aggregate. The specific gravity of the combined aggregate has been adopted as (PG=2.63) based on the experimental results, and consequently the calculated value of $\propto$ was 1.007. The specific surface area of aggregate was expressed by a € symbol which depend on the selected aggregate gradation. It represents the function of the proportions of aggregate retained on some specific sieves (G, S, s, f). These proportions obtained from selected gradation (mentioned previously in Figure-1.) were: G=48%, S=42%, s=5% and f=5%, consequently, the calculated € value was 9.186. The previous calculated parameters give minimum binder content equal to 5.34% of the total mix.

The OBC (5.5%) from Marshall mix design is higher than the minimum binder content (5.34%).Thus, the related value of richness modulus according to optimum binder content (5.5%) was 3.71 which is satisfying the EME requirements.

Workability evaluation results

In this research, the SGC was used for workability evaluation according to the equipment availability, the same trends of using different types of gyratory compactor for EME mix performance were adopted by previous studies [5, 11, 45]. The density at design number of gyratory (Ndes, 120) was (2.333 gm/cm^3), while the maximum density (Gmm) was determined from the laboratory test at OBC equal to 2.43 gm/cm^3. According to the obtained results of SGC test, the (AV %) at N des was (4.0%) for AC 20-EME 2 as shown in Figure-3.

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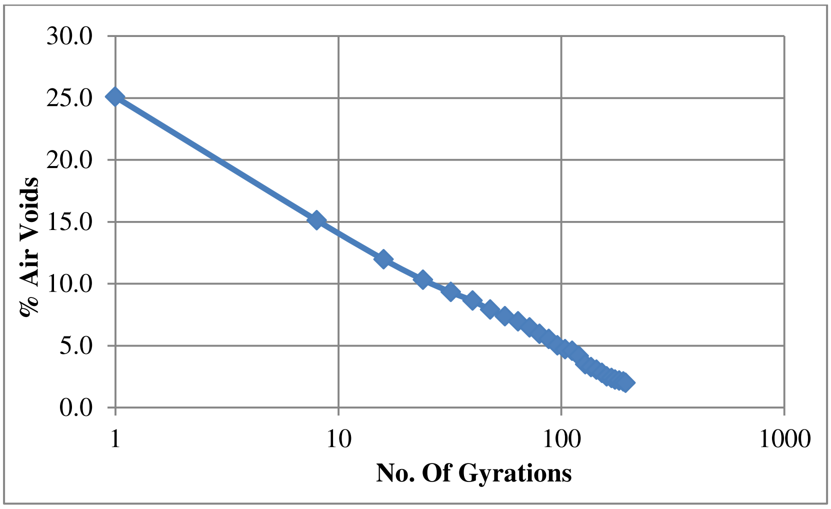

Figure-3. The relation between air voids and no. of gyrations.

The (AV %) at OBC (for specimens prepared with both impact and gyratory compactor) was less than 6% which represents the maximum voids content required by EME method. The satisfying of AV% means that the workability requirement of the HMAC mix according to EME2 has been achieved.

Performance test results

Moisture sensitivity test results

The obtained results showed that HMAC mix has higher resistance to stripping. This can be observed from the high value of Indirect Tensile Strength (ITS) for HMAC mixture than conventional mixtures. It is more than the conventional mixture by about 2.1 times for conditioned specimen, and 1.7 times for unconditioned specimens as shown graphically in Figure-4.

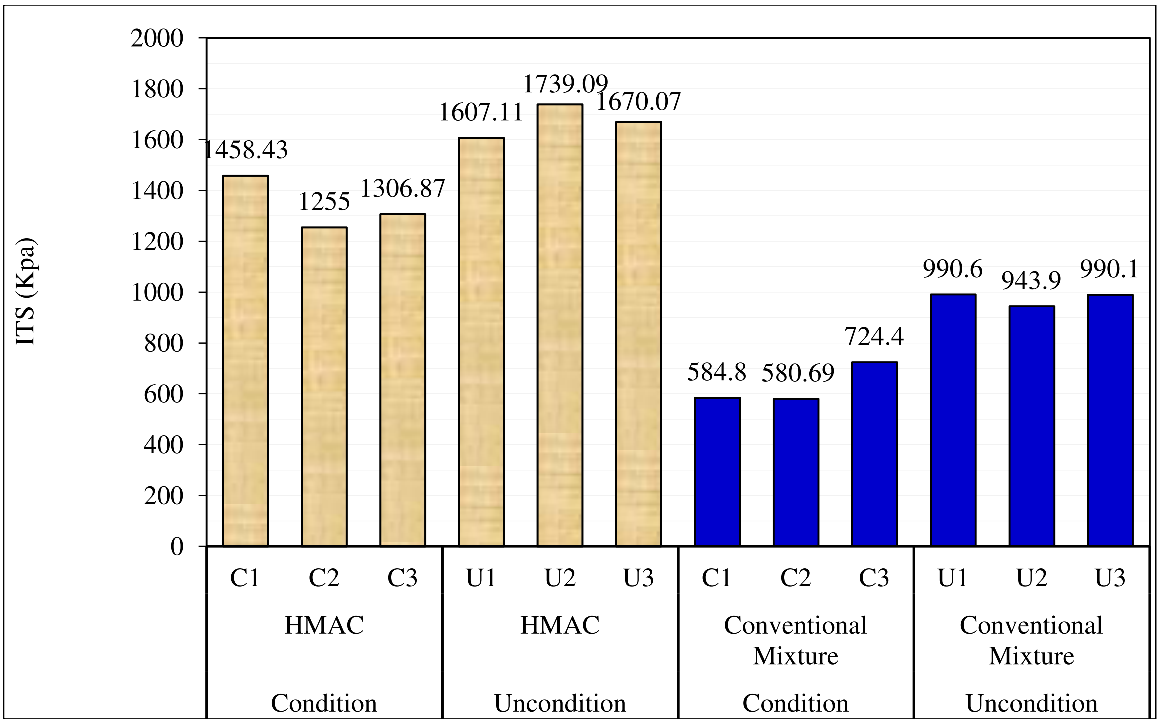

Figure-4. Indirect tensile test results.

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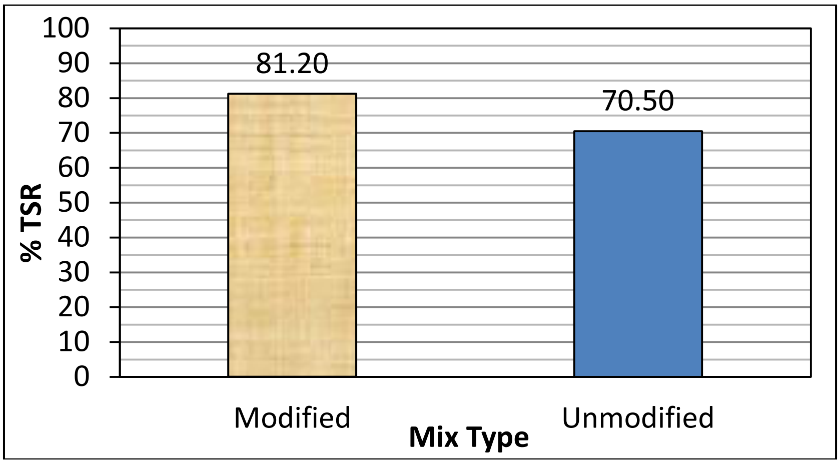

Figure-5. Moisture sensitivity test result.

The obtained value of TSR for HMAC mixture was 80 %. which is higher than conventional mixture (65 %) by about 24% as shown in Figure-5. It satisfies the required standards of moisture sensitivity of EME (TSR ≥70%). The results revealed that HMAC can resist high strains prior to failure and consequently it resist cracking more than conventional mixture. The better performance of moisture resistance for HMAC is mainly due to the higher viscosity of bitumen binder (15-25) compare to conventional bitumen (40-50) and the higher binder content. Thus, it provides an adequate retention of bitumen binder on the aggregate surface in HMAC.

Rut resistance test results

The obtained results of the wheel tracking test for two types of asphaltic mixture (conventional and HMAC) revealed that HMAC mixtures showed a significant improvement in rutting resistance compared to the conventional mixture regarding to the reduction in the rut depth value as can be seen in Figure-6. This figure showed that the rut depth values for two slab specimens of HMAC are (4.5 mm) and (6.15 mm) at 10000 cycle which approximately equal to 7.5% and 10.25% of the slab thickness (60mm). While the two slabs of conventional mixture were showed a rut depth of 20 mm before completing the required number of cycles of test (7000 and 8000 cycles respectively). Even the adopted test procedure is differ than that recommended by EME method, the obtained results for rutting (permanent deformation) for HMAC are very close to the requirement of EME (7.5 % from the thickness of specimen). The using of hard grade bitumen and the design method of EME (even it is not followed exactly) gave this significant improvement.

This improvement could be related to the high viscosity and low thermal susceptibility of hard grad bitumen (15-25) compared to conventional bitumen (40-50) this agree with some researches in this aspect [37]. Also the high quality of aggregate may play vital role in this aspect [14]. Furthermore, the presence of CR in hard grade bitumen made the asphalt mixture more resistance to plastic deformation since it enhance the viscosity and flexibility of the bitumen at the same time [7, 8]. The obtained results of permanent deformation test for HMAC were comparable to the results of several researches that adopted the same test method (wheel track test by small device) in rutting evaluation of HMAC mixture [3, 7, 8]. Figure-7 shows the permanent deformation of specimens (conventional and HMAC) at the end of test.

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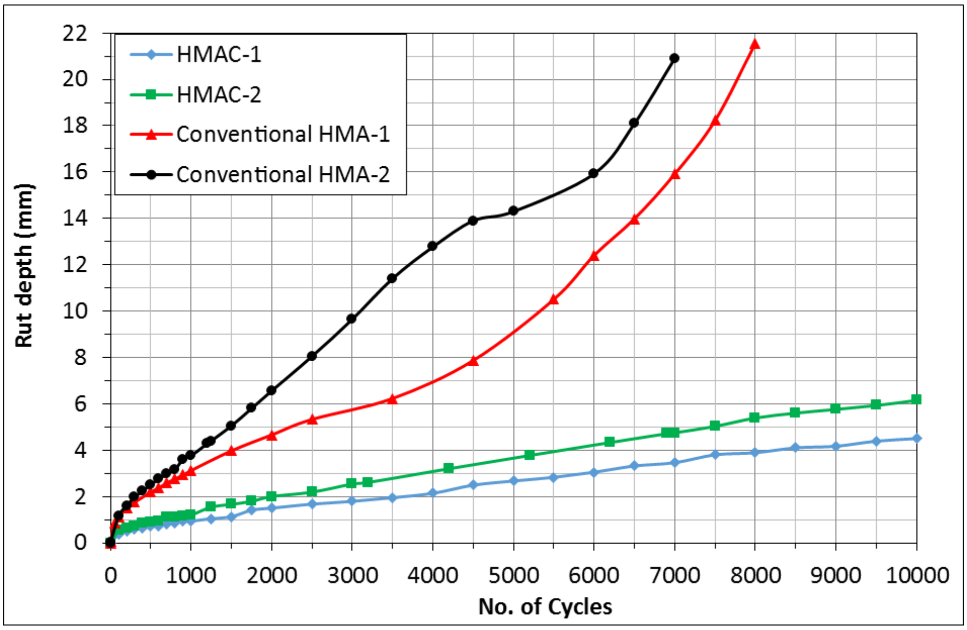

Figure-6. Rut depth result in wheel tracking test.

Stiffness modulus results

Four samples were tested for each HMAC and conventional mixes to determine the stiffness modulus. Each sample was subjected to five load pulses and the average value of these pulses was calculated according to BS EN 12697-26 Annex C. The average value for the stiffness modulus for HMAC of the four specimens was (9394.5 Mpa) even this value is less than requirement of EME design method but it is more than the average value of stiffness modulus (2608.75 Mpa) for conventional mixture by about 3.6 times as shown in Table-4. This difference (regarding EME2 requirement) may be related to change the recommended test procedure for EME method, similar trend of results was observed when some researchers [4] used 4PB-PR (Four Point Bending test on Prismatic specimen) instead of 2PB-TR (Two Point Bending test on Trapezoidal specimen). The improvement in stiffness modulus may be related to using hard grade bitumen also it may be related to other requirements of design method such as using high quality of aggregate and using no hydrated lime.

The samples containing CR with HMAB did not show significant change in stiffness modulus as shown in Table-5. The addition of CR could slightly improve stiffness (elastic) modulus as observed in literature [8, 46]; however, it could improve the fatigue resistance more [47, 48].

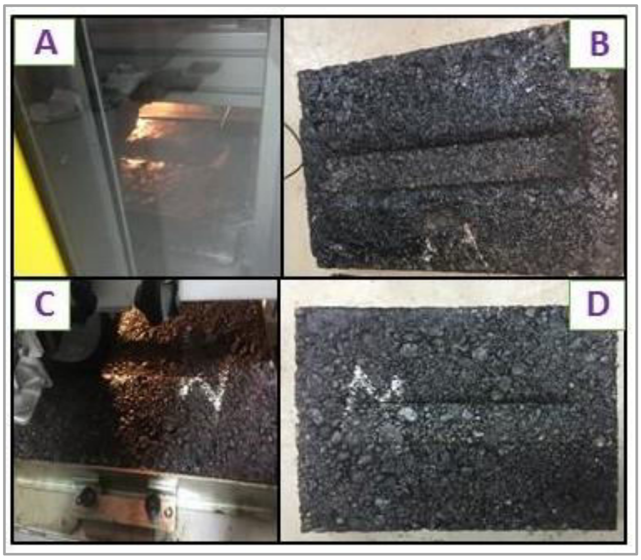

Figure-7. Final rut depth for (A), (B) slabs with conventional mixture (C), (D) slabs with HMAC mixture.

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Table-4. Indirect tensile stiffness test results.

Mixture type	Conventional mixture (40-50)	HMAC mixture (15-25)
	Resilient modulus (MR) value, MPa	**Resilient modulus (MR) value, MPa**
Specimen 1	2485.99	9027
Specimen 2	2364	8097.57
Specimen 3	2702	10899.6
Specimen 4	2383	9554
Average	2608.75	9394.5

Table-5. Indirect tensile stiffness test results for HMAC modified with CR.

HMAC modified with CR	Resilient modulus (MR) value, MPa
Specimen 1	9518
Specimen 2	9008
Average	9263

Results of estimated fatigue life and reduction in thickness

Based on the obtained results from KENPAVE program, the tensile strains at bottom of 6 in asphaltic concrete layer of HMAC and conventional mixture were (0.00009878) and (0.0001975) respectively. The fatigue life (in terms of number of repetition of traffic load) of pavement sections containing HMAC and conventional mixture were (5.250E+07) and (7.306E+06) respectively. The results of estimation showed that the HMAC mixture can carry about 7.2 times of axle-load applications more than the conventional mixture before exhibited fatigue cracks. Regarding to reduction in thickness, firstly, the FAARFEILD program proposed the adjustment by amended thickness of base layer (layer in contact with asphaltic concrete layer); the obtained reduction in thickness of base layer of HMAC pavement section was equal to (3.7 in) as shown in Figure-8 and Figure-9. This attributed to the high elastic modulus of HMAC pavement layer as compared to the elastic modulus of conventional pavement layer. secondly, the calculations of reduction in thickness in asphaltic concrete layer of pavement were based on conducting a parametric study using KENLAYER program to change the thickness of asphaltic concrete layer of HMAC and comparing the pavement responses (total displacement on top surface, the horizontal strain underneath asphaltic concrete layer and the vertical (compressive) strain acting on subgrade) with that of asphaltic concrete layer of pavement implemented by control mix which has thickness of 6 inches. Several trails have been made with different thickness of HMAC layer to select the asphaltic concrete layer thickness which induced the same or smaller than above mentioned responses induced by control section. The suggested thicknesses of HMAC layer were started by 3.5 in. with increment of 0.25 in. until reaching approximately similar response of control mix with 6 in thick. The selected thicknesses and the calculated responses of pavement and fatigue life are illustrated in the Table-6. The chosen asphaltic concrete layer thickness of HMAC was 4 in., which resulted in pavement response smaller than what was induced by conventional mixture with 6 in thickness of control mixture. Therefore, the obtained thickness reduction was 2in. in asphaltic concrete layer; which is equal to 33 % reduction in asphaltic concrete layer thickness. This reduction can significantly reduce the cost of construction of roads using the obtained HMAC mixture obtained from this research.

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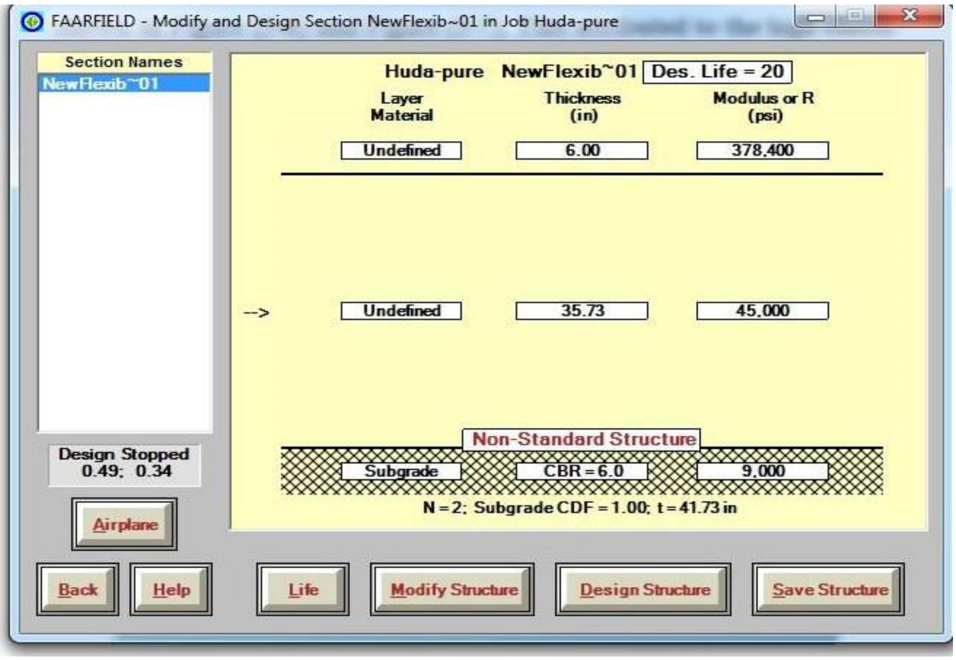

Figure-8. Design of layers thickness for pavement containing conventional mixture.

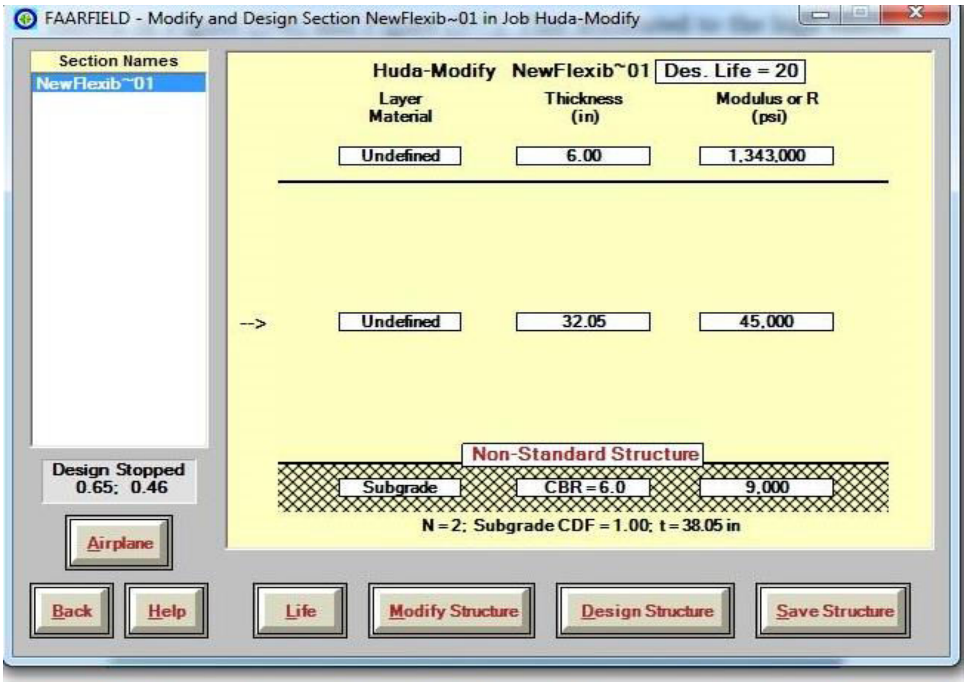

Figure-9. Design of layers thickness for pavement containing HMAC mixture.

Table-6. Pavement response of HMAC and Conventional pavement sections.

Pavement response	**HMAC** (3.5 in. thick)	**HMAC** (3.75 in. thick)	**HMAC** (4 in. thick)	**HMAC-** (6 in. thick)	**Control HMA** (6in thick)
Horizontal tensile strain	1.618E-04	1.538E-04	1.462E-04	9.878E-05	1.975E-04
Vertical strain	3.270E-04	3.062E-04	2.871E-04	1.800E-04	2.828E-04
Total displacement	0.01983	0.01911	0.01844	0.01423	0.01893
Fatigue life	9.457E+06	1.016E+07	1.169E+07	5.250E+07	7.306E+06

SUMMARY AND CONCLUSIONS

The research involved experimental programme to produce HMAC according to EME2 mix design method using the hard grade bitumen produced in novel way by the authors. The procedure recommended by EME2 was followed as much as possible; however, some alternative test techniques (mentioned in the same reference standard for EME) were adopted due to lack of some test equipments. The experimental programme involved testing of workability, resistance to moisture damage, stiffness modulus and rutting resistance. The results of study showed a significant improvement of HMAC properties compared to conventional mix. The moisture damage resistance increased by 24 % for HMAC compared with conventional mix, and the stiffness modulus of HMAC was found equal to 3.6 times of the conventional mix. The rutting resistance was also increase for HMAC by about 4.5 times of conventional (control) mix.

In order to investigate the effect of this improvement in mechanical properties of HMAC on thickness and consequently construction cost of pavement, analytical procedure and software programmes were used to estimate the reduction in thickness and the fatigue life of produced HMAC. The results showed that HMAC pavement can carry about 7.2 times axle-loads compared to conventional HMA before initiation fatigue cracking failure. The reduction in thickness was about 33% of thickness of asphaltic concrete layer which consequently, reduce the construction cost of roads significantly.

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