Studying the Effect of Synthetic Zeolite on Properties of Warm Mix Asphalt

دراسة تأثير الزيوليت الصناعي في خواص المجبول الإسفلتي الدافئ

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ABSTRACT

Warm mix asphalt (WMA) technology allows for lower production Hot Mix Asphalt (HMA) production temperatures by)20-40(°C and achieves economic and environmental benefits through energy savings and reduced emissions of carbon dioxide (CO2) and other gases that pollute the environment and are harmful to the health of workers and employees in this field. The purpose of this research is to evaluate the use of Synthetic zeolite in the manufacture of warm asphalt mixes and studying the changes in properties of warm mix asphalt compared to the properties of hot mix asphalt. The synthetic zeolite, bituminous binder, and aggregates used in this study were characterized and described. Two types of asphalt mixtures were done according to the Marshall method at varying asphalt binder contents (4-7%): Hot mixtures and warm mixtures containing 0.3% of synthetic zeolite by the total weight of the asphalt mix, all asphalt mixtures have been prepared from two asphalt grades (60/70, 85/100) and single aggregate source. the changes in the properties of warm asphalt mixtures modified with Synthetic zeolite were investigated and compared with reference mixtures with indicators such as Density, Marshall stability, Flow and Air voids. Results of Marshall tests indicate the success of the Synthetic zeolite in production of WMA temperatures at 135C°, in which the physical and mechanical properties of the WMA were close to the properties of the hot mix asphalt.

Keywords: Hot mix asphalt, Warm mix asphalt, Synthetic Zeolite, Marshall test.

الملخص

تسمح تكنولوجيا المجبول الإسفلتي الدافئ بتخفيض درجات حرارة انتاج المجبول الساخن بمقدار (20–40)°C، بالإضافة إلى تحقيق مجموعة كبيرة من الفوائد الاقتصادية والصحية والبيئية من خلال الوفر الحاصل بالطاقة وغيرها من الغازات الملوثة للبيئة والمؤذية لصحة العمال والعاملينCo2المستهلكة وتقليل انبعاث غاز ثاني أوكسيد الكربون في هذا المجال. يهدف هذا البحث إلى دراسة إمكانية استخدام الزيوليت الصناعي في إنتاج المجبول الإسفلتي الدافئ، ودراسة تم في هذه الدراسة تحديد خواص الزيوليت .التغيرات الحاصلة في خواصه بالمقارنة مع خواص المجبول الإسفلتي الساخن عند نسب رابط الصناعي والروابط الإسفلتية والحصويات المستخدمة، وتصميم نوعين من الخلطات الإسفلتية وفق طريقة مارشال اسفلتي متغيرة (4-7%): الخلطات الإسفلتية الساخنة المرجعية، والخلطات الدافئة المعدلة بالزيوليت الصناعي عند نسبة وزنية واحدة (0.3%) من الوزن الكلي للمجبول الإسفلتي، حيث تم تصنيع جميع الخلطات الإسفلتية باستخدام نوعين رابط بيتومين (60/70، 85/100) ونوع واحد من الحصويات الكلسية. تم تمت دراسة التغيرات الحاصلة في خواص الخلطات الإسفلتية الدافئة المنتجة باستخدام بالزيوليت الصناعي ومقارنتها مع الخلطات الإسفلتية الساخنة المرجعية باستخدام بارامترات مارشال المعروفة تُشير نتائج اختبارات مارشال إلى نجاح الزيوليت الصناعي في إنتاج المجبول .من ثبات وانسياب وكثافة وقيم الفراغات الهوائية الإسفلتي الدافئ عند درجات حرارة إنتاج 135°C، وبخواص فيزيائية وميكانيكية جيدة وقريبة من خواص المجبول الساخن.

الكلمات المفتاحية: المجبول الإسفلتي الساخن، المجبول الإسفلتي الدافئ، الزيوليت الصناعي، اختبار مارشال.

INTRODUCTION

Warm mix asphalt has been used over the past few decades as an alternative to hot mix asphalt in order to achieve a wide range of environmental, economic, and engineering benefits. These include reducing the temperatures required for the production and compaction of asphalt mixtures, lowering the energy needed for production, and decreasing emissions of gases and fumes. It also improves working conditions in asphalt plants and paving sites, which in turn has a positive impact on workers' health. Additionally, it results in lower energy consumption, enhanced safety, slower aging of the asphalt binder, and improved properties of the asphalt mixture. It allows the mixture to be transported over longer distances while maintaining its workability, enables placement in thicker layers,

facilities opening to traffic within a short period and supports the use of higher percentages of recycled paving materials [1,-4].The mixing temperatures of warm mix asphalt mixtures ranged from 100°C to 140°C compared to the mixing temperatures of 150-180°C for conventional hot mix asphalt. WMA technologies are commonly classified as those that use foaming techniques, organic or wax additives, and chemical additives [5-7].Synthetic zeolite is considered a hydro-thermally mineral that contains about 21% by weight of water, which is released from the zeolite structure as the temperature increases. It is produced by chemical reactions between sodium silicate (Na2SiO3), sodium aluminate (NaAlO2), and various silicate and aluminate-bearing materials such as fly ash, clay minerals, and perlite, under specific conditions of varying temperatures, pressures, and reaction times. The addition of zeolite into the asphalt mix causes the release of the crystalline water and forming a micro-foaming effect in the mix, which leads to the expansion of the binder volume and reduced viscosity. It facilitates better coatings of the asphalt on aggregates at lower temperatures during the production process, transport and the laying of the asphalt mix [8-12]. In 2005, Hurley and Prowell conducted the first laboratory study on the use of synthetic zeolite in production of WMA. Their study included the use of two types of aggregates (granite, and limestone), two types of asphalt binders (PG 64-22 and PG 58-28) and Aspha-Min additives. WMA samples were compacted at temperatures (149, 129, 110, 88)°C, and the mixing temperatures were twenty degrees higher than the compaction temperature, Laboratory tests indicated an improvement in the compaction of WMA samples involving synthetic zeolite regardless of the type of asphalt, the type of aggregates and the compaction temperature. On the other hand, the lower compaction temperature used when producing warm mix asphalt with Aspha-min® may increase the potential for moisture damage. Hence, the addition of 1.5% hydrated lime has resulted in acceptable performance [12]. Mohamed et al. (2025) evaluated the performance of half warm mix asphalt(HWMA) prepared with Synthetic zeolite and addressed the gap in comparative analysis between HWMA and HMA by conducting comprehensive tests, including indirect tensile strength (ITS), loss of stability and scanning electronic microscope (SEM). This paper concluded that HWMA modified with 10% Synthetic zeolite, 5% epoxy and 10% stearic acid achieved higher ITS values and reduced susceptibility compared to HMA. It was also concluded that HWMA's potential as a sustainable and high performance alternative to HMA without compromising mechanical properties [13].Sağlık et al. (2016) used Synthetic zeolite (Aspha-Min) in production WMA and evaluated the properties of warm mix asphalt. They used bitumen 50/70 and added Synthetic zeolite at 0.3% by total weigh of asphalt mixtures. The results indicated that the performance of WMA was comparable to hot mix asphalt in terms of rutting and fatigue resistance, while a slight reduction in the moisture resistance of the warm mixtures [14].Bichajło et al. (2025) used zeolites to enable reconciliation of technological requirements of mastic asphalt and asphalt roof isolation. the mixtures containing 0 and 5% of two types of zeolites and asphalt binders 35/50 or elastomer-SBS-modified asphalt binder PMB 25/55-60 were used in their study. Laboratory results revealed that the addition of a 5% amount of zeolite by asphalt mass makes it possible to decrease the mastic asphalt laying temperature by 30 °C, which could be very important to achieve environmental and economic goals and pavement durability [15].Some studies found that the moisture resistance of WMA formulated with zeolite decreased compared to hot asphalt mixes when the production temperature of the asphalt mix decreased [16,17]. While other studies indicated an improvement in the indirect tensile strength modulus (ITSR) of warm asphalt mixes containing zeolite as they decreased in production temperature [18].

objectives:

WMA is a new topic in Syria, and there aren't a lot of studies in the Arab world of production WMA concrete using Synthetic zeolite. Therefore, the aims of this work are:

1) Investigate and evaluate the influence of Synthetic zeolite additives on physical and mechanical properties of warm mix asphalt.
2) Achieving economic goals through cost savings in asphalt mix production due to the reduced energy and fuel required.
3) Production environmentally friendly asphalt mix by reducing the emission of gases and odors from asphalt plants, in addition to preserving the health of workers in this field.

MATERIAL CHARACTERISTICS

1.Asphalt binder:

Two Asphalt binder grades were used in this study (60/70, 85/100) obtained from Homs and Baniyas Refinery Company. The Physical Characteristics of Asphalt binder were tested according to standard specifications are listed in table 1.

Table 1: Physical Characteristics of asphalt binder				
Test	Test Result		ASTM Specifications	
			60/70	85/100
Penetration (ASTM D.5)	61.5	98	60-70	85-100
Ductility (ASTM D.113), cm	150	150	100> cm	
Softening Point (ASTM D.36), °C	47.8	45.8	54-46	43-51

Aggregates:

The coarse and fine aggregates were supplied from Hsia City. The gradation of the test specimens was performed in accordance with ASTM of surface course, Fig.1 shows gradation of these aggregates. It has been selected and incorporated in preparing all asphalt concrete mixes used in this study. The mechanical and physical characteristics of used aggregates have been tabulated in table 2.

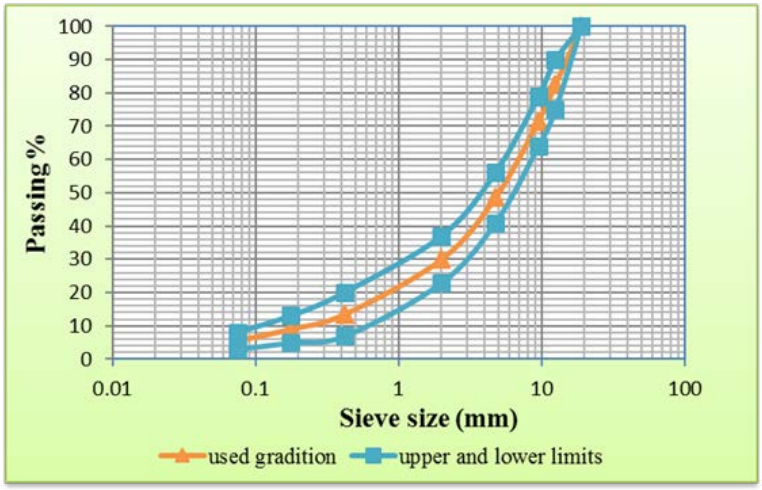


Fig 1: Aggregates gradation of asphalt concrete

Table 2: Mechanical and physical characteristics of aggregates	
Test	Test Result
Resistance of Abrasion (ASTM C.535)	18.7%
Sand Equivalent (ASTM D.2419)	74.4%
Effective specific gravity of aggregate	2.638

3.Synthetic zeolite:

•Synthetic zeolite samples used in this study imported from the People›s Republic of China. Table. 3 presents the chemical analysis of the synthetic zeolite samples, indicating that synthetic zeolite consists mainly composed of silica (SiO2) and alumina (Al2O3) that constitute the zeolitic structure in addition to its high crystalline water content.

Table 3: Chemical composition of Synthetic zeolite							
Oxide	Sio_2	Al_2o_3	Cao	Tio2	K2o	Na2o	H2o
Wt%	41.03	28.13	0.05	9.53	0.21	0.05	21

•Experimental Methods:

There are no local specifications to production WMA mixtures and a possible reduction in WMA mixing and compaction temperatures depends on trial studies, type of additives and recommendations of companies producing it. However, zeolite additives allow reduction in the production placement temperatures of (20-30)ºC with the HMA[19-

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[22]. The possibility of using synthetic zeolite to produce WMA mixtures has been investigated. WMA samples were manufactured according to the Marshall test (ASTM.D 1559) at a mixing temperature of 135ºC and a compaction temperature of 125ºC. synthetic zeolite additives were crushed with grain size of 0-0.075mm (passing from No.200) and added to aggregates at the rate of 0.3% of the mix at the same time with asphalt and mixed.



Fig. 2: Production of WMA samples

RESULTS

Effect of synthetic zeolite on asphalt mixtures characteristics:

•Figures (3-6) show the design results of reference hot asphalt mixes and warm mixes containing 0.3% synthetic zeolite at varying asphalt contents (4-7%), where Marshall curves were drawn and the ideal asphalt ratio was determined on each curve, achieving maximum density, maximum stability, and average technical requirements for flow and air voids. Table (4) shows the properties of hot and warm asphalt mixes at the optimum asphalt ratios.

•The changes in the properties of warm asphalt mixtures modified with synthetic zeolite were investigated and compared with reference mixtures. Marshall Properties at optimum asphalt content results has been tabulated as shown in Table. 4.

Table. 4: Marshall properties of HMA and WMA mixtures at optimum asphalt content

Mix type	Optimum asphalt content (%)	Marshall Stability (Kg)	Marshall flow (mm)	Density (g/cm3)	Voids in total mix (%)	Marshall quotient (KN/mm)
$HMA_{60/70}$	5.4	1420.67	3.49	2.346	3.6	4.07
$HMA_{85/100}$	5.1	1306	3.70	2.343	4	3.52
$WMA_{60/70}$	5.8	1262	3.64	2.319	4.2	3.05
$WMA_{85/100}$	5.6	1101.33	3.79	2.320	4.3	2.9

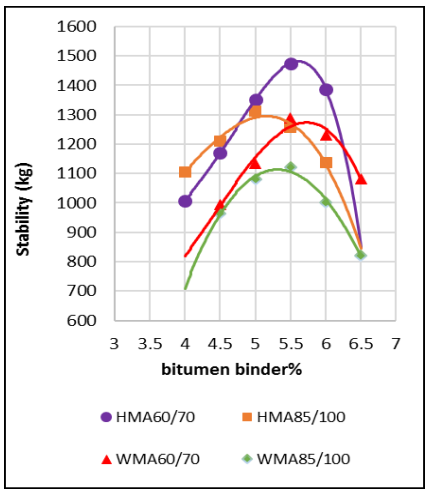


Fig. 3: stability values for asphalt mixture types

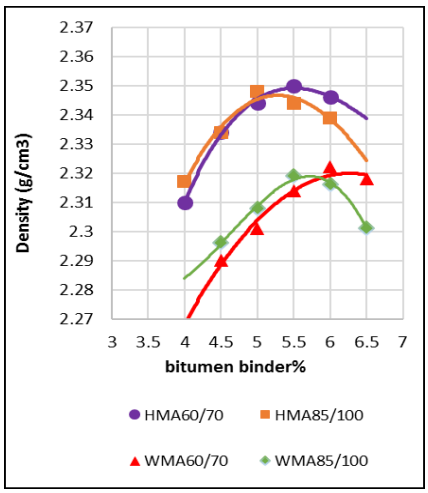


Fig. 4: Density values for asphalt mixture types

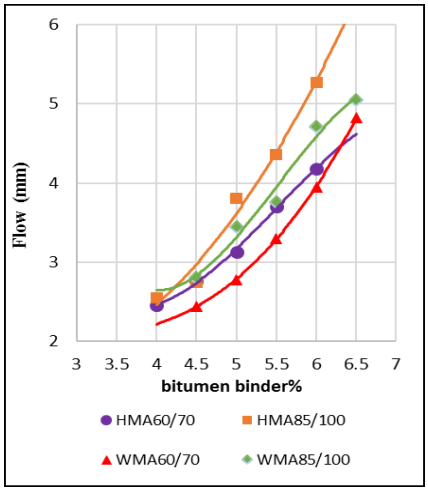


Fig. 5: flow values for asphalt mixture types

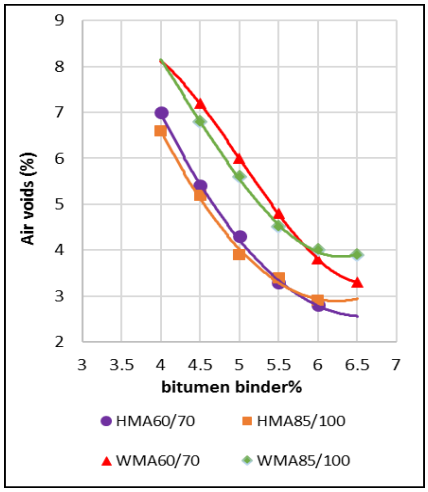


Fig. 6: Air voids values for asphalt mixture types

Fig. 7 shows the test results of Marshall stability for all mixtures. The results show that the Marshall stability for all mixtures were acceptable as compared with the specification limits (Min. 800kg) [ASTM].

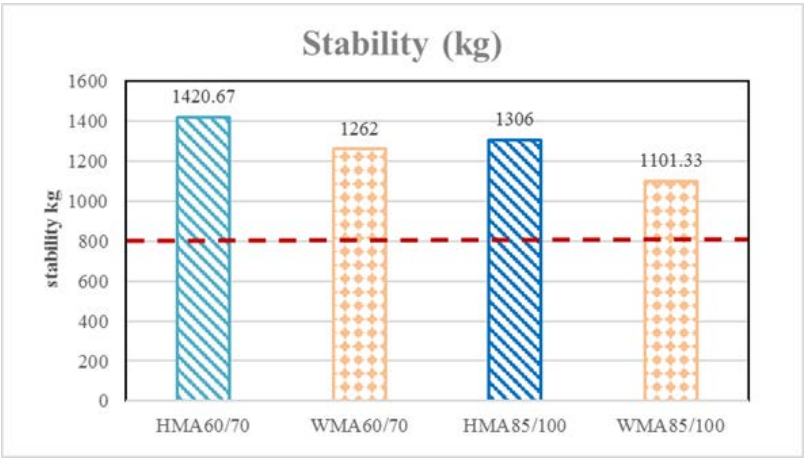


Fig. 7: Marshall stability values of different asphalt mixture types

Marshall stability values indicate a decrease in the stability values of warm asphalt mixes designed using synthetic zeolite. Marshall stability values decreased by 11% for mixes designed using asphalt 60/70 and by 16% for mixes designed using asphalt 85/100. This decrease in stability values is attributed to the reduction in heat energy used during its production. Consequently, the role of synthetic zeolite comes into play in maintaining good stability values within the limits of the acceptance specifications (<800kg). The good stability values can be attributed to the role of synthetic zeolite in creating foam in the asphalt mix and improving its workability. Figure. 8 shows the flow of warm and hot asphalt mixes and Marshall quotient coefficients at optimum asphalt binders, where the results

were within the acceptable specifications limits of (2-4)mm.These changes were accompanied by a decrease in the resistance to permanent deformation of the warm mixes, expressed by a decrease in Marshall quotient coefficients, while remaining within the acceptable specifications limits.

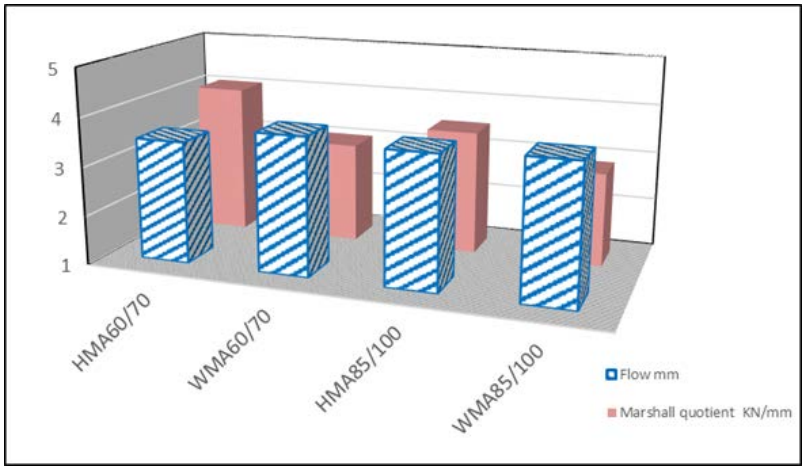


Fig. 8: Flow and Marshall quotient values of different asphalt mixture types

Figure. 9 shows the changes in the values of air voids for warm asphalt mixes where it is noted that the values of air voids for warm mixes increase compared to hot mixes, while remaining within the limits of the acceptable specifications (3-5)%.

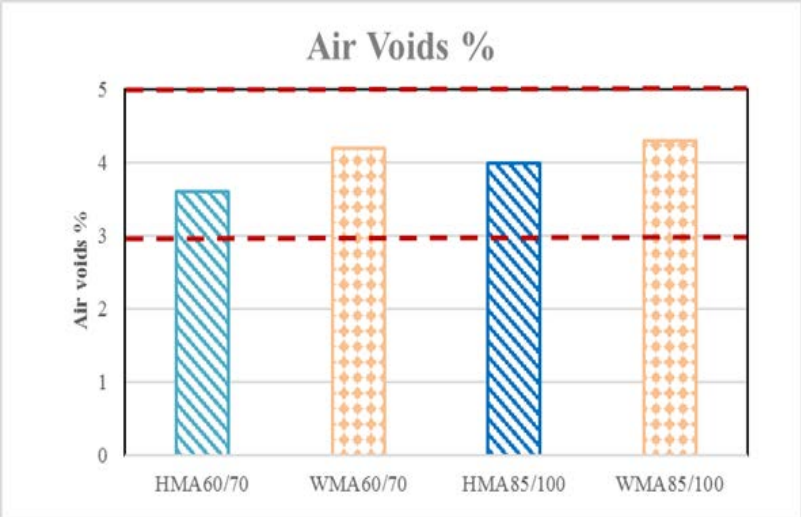


Fig. 9: Air voids values of different asphalt mixture types

Warm asphalt mixes showed a significant increase in the required asphalt binder ratios, as shown in Figure. 10.

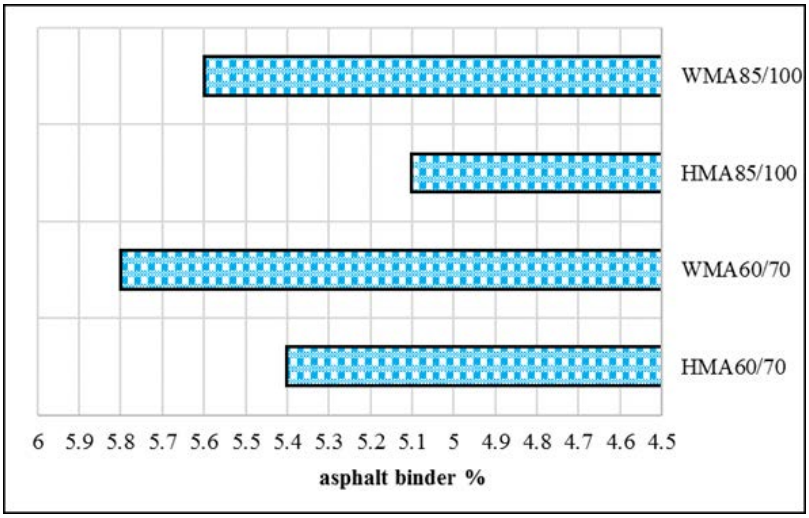


Fig. 10: Optimum asphalt content of different asphalt mixture types

DISCUSSION

The results of Marshall tests indicate to decrease in stability and density and increase in flow and air vales of warm mix asphalt. Marshall stability values decreased by 11% for mixes designed using asphalt 60/70 and by 16% for mixes designed using asphalt 85/100. it could be due to the lower thermal energy used during production. Consequently the role of synthetic zeolite becomes important in maintaining acceptable stability values within specification limits (800>kg). The relatively good stability values can be attributed to the ability of synthetic zeolite as a foaming additives in improve workability of asphalt concrete. These results are consistent with previous studies related to synthetic zeolite additives [23-25].The Marshall quotient (MQ) expresses the ratio between stability and flow, and is used to determine the resistance of asphalt mixtures to permanent deformation (rutting). The higher the value of this quotient, the greater the resistance of asphalt mixtures to permanent deformation. The result showed a decrease in the permanent deformation resistance of the warm mixes, expressed as a decrease in Marshall stiffness indices, while remaining within the acceptable specification [26,27].Warm asphalt mixes showed an increase in the required asphalt binder ratios. The required binder ratio for $WMA_{60/70}$ warm mixes increased by 7%, and by 10% for $WMA_{85/100}$ mixes. These changes are consistent with the results of previous studies regarding the increased need for binder with decreasing production temperatures [23-25]. The changes in the properties of warm asphalt mixtures at optimum asphalt content was investigated. The results showed good physical and mechanical properties of WMA compared with HMA. However, the stability decreased by 16% while maintaining flow values and air voids within the limits of the specifications (flow: 2-4mm, air voids 3-5%) [ASTM]. The changes in void values demonstrate the role of synthetic zeolite in maintaining the compactability of warm asphalt mixes. This result is consistent with the results of previous studies [12,28].

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

Based on the results of studying the effect of synthetic zeolite in asphalt concrete mixtures, it can be deduced:

1.The successful use of synthetic zeolite in production warm mix asphalt with good physical and mechanical properties within specification limits.

2.An increase in the optimum asphalt binder content was observed in certain WMA mixtures, depending on the type of additive and aggregate characteristics, which can be attributed to reduced binder absorption by aggregates at lower production temperatures

3.Results of Marshall tests showed decreasing in stability values of warm mix asphalt compared to hot mix asphalt, while flow values and air voids decreased.

RECOMMENDATIONS

1.Study the performance of the warm mix asphalt involving synthetic zeolite such as rutting potential and fatigue life.

2.Study the effect of other additives (organic and chemical additives) on the characteristics of asphalt binder and WMA mixtures.

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Author contributions: Mahmoud abdullh

Ethical Approval: Oral informed consent was obtained from parents/guardians and assent from adolescents, in accordance with the Declaration of Helsinki and CIOMS guidelines for research in conflict settings. Consent to publish Not applicable (the manuscript contains no individual person's identifiable data).

Data Availability Statement

All data are available in the main text or the supplementary materials.

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