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Evaluating the mechanical performance of hot asphalt mixtures modified with metakaolin as filler

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ABSTRACT

Filler has an essential effect on the behavior of the hot asphalt pavement mixtures (HMA) through reducing the voids in the aggregate skeleton and reducing the temperature susceptibility of the asphalt binder layer. Recently the use of Metakaolin as a Pozzolanic admixture has been investigated to enhance the strength of cement concrete mixture. In this study, an experimental assessment of the mechanical properties of the HMA modified by Metakaolin as partial replacement of cement mineral filler was conducted. Five mixtures containing 0, 25, 50, 75, and 100 Metakaolin replacements percentages of ordinary cement were prepared at their optimum asphalt content. The Marshall properties, temperature susceptibility, and moisture damage are investigated for these mixtures. It was found that the addition of different proportions of Metakaolin filler as replacement of cement has a significant influence on the mechanical behavior of the HMA. The result illustrated that The Marshall's Stability, Flow and, density grow as the Metakaolin content grows until 50%, then the value starts to decrease at 75 and 100%. The air voids and voids in mineral aggregate decrease with increase the Metakaolin content to the lowest value at 50% of Metakaolin. The indirect tensile strength increases continuously as the Metakaolin content increases at 25, 40, and 60 ^{o}C, while temperature susceptibility decreases as Metakaolin content increases. The resistance to moisture damage has been improved by adding Metakaolin filler. It is concluded that the hot asphalt mixture can be modified by using Metakaolin as partial replacement mineral filler at 50% and optimum asphalt content of 5.2 %.

Keywords: Metakaolin, Temperature susceptibility, Moisture susceptibility.

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1. Introduction

Highway infrastructures have a significant role in the local and international studies of developing urban cities because of its direct and indirect effect on the growth of urban areas, environmental issues, and socio-economical problems. Therefore, experts and researchers have been paying significant attention to the structural design of highways pavement as it is the most costly part of the highway infrastructures. The main points considered in evaluating and improving the performance of pavements are evaluating and improving pavement materials characteristics.

The material of mixtures used in constructing the pavement surfaces should be higher quality than the materials used in underlying courses to produce high performance pavement structure. This leads to making the construction projects of the highway more costly. Therefore, researchers have been focusing on finding alternative materials for the different courses of the pavement structure to overtake the economic challenges of highway construction and keep their structural performance at a higher level [1].

Modifying the mixture design of the pavement surfaces, especially asphalt surfaces, is the most common technique considered in the pavement material research. The behavior of the hot mix asphalt (HMA) in terms of their strength and stability is affected by some characteristics by the properties of the used aggregate in terms of quality, quantity, and grading. Fillers, which are the aggregate materials finer than 75μm in size, have a strong influence on the performance of the asphalt pavement mixtures [2].

Mineral fillers are added to the graded HMA to improve its physical properties. Using fillers improves the density and stability of HMA by reducing the voids in the coarser aggregate [3]. It also plays a role in dropping the temperature susceptibility of the asphalt binder layer [4].

Portland cement is one of the most common types of fillers used in the HMA. However, the fundamental constituent of cement is not considered environmentally friendly materials because the production of Portland cement exhausts large quantities of natural resources as well as releases a lot of Carbon dioxide (CO_2) and other greenhouse gases. The output of one ton of cement emits about one ton of (CO_2). Therefore, to avoid the environmental impacts related to the production of Portland cement, there is a need to find alternative materials [5].

Recently, waste materials and less energy manufactured material that have cementitious properties are globally used as a filler and highly addressed by the HMA researcher. Pozzalanas is an example of this type of material. It can be found in several forms, such as fly ash and limestone dust. This alternative is considered one of the most cost-effective fillers [6].

Metakaolin (MK) is recognized as calcined clay that has pozzolanic behavior. It is obtained from processing high-quality kaolin clay in high-temperature circumstances, about 650-800^{o}C, for 90 minutes [7]. Several researchers studied using MK as a filler and how it affects the behavior of the construction materials. Murray [8] studied the effect of MK on cement concrete properties. He found that MK has active Pozzolanic behavior, which can improve the strength properties of cement concrete mixture.

Murana et al. [9] investigated the effect of adding the MK as a partial percentage of cement additives on the mechanical properties of the HMA using Marshall Tests. In this research, the optimum bitumen content that keeps the stability, flow, voids in mixed aggregates, and voids in the whole mix within the limits of the standard specification were determined. He found that using an optimum bitumen content of 5.5% with a mix of cement and the MK fillers led to improving the performance of the HMA.

Satar et al. [10] studied the modifying of the HMA by adding different percentages of the MK filler by weight to the HMA. He used 2%, 4%, 6%, and 8% as four alternatives of filler percentages by the binder weight. He demonstrated the useful role of the MK as a replacement for the joint fillers. He also found that using 2% of the MK as filler produces a high level of HMA performance in terms of its stability and stiffness.

Based on this review, the main aim of this paper is set to assess the mechanical properties in terms of mix design, temperature susceptibility, and Moisture susceptibility of asphalt mixtures containing Metakaolin as a partial replacement of cement filler.

2. Materials and research methodology

2.1 Materials

The material used in this study represents the material needed to design the asphalt mixtures of flexible pavement in addition to the proposed filler additives, which, is the MK material. In order to simulate the actual performance of asphalt pavement of local roads constructed in Iraq with the laboratory atmosphere as possible, the needed materials are brought from local sources and widely used in constructing the road in Baghdad.

2.1.1 Asphalt cement

The asphalt binder of (40-50) penetration graded was used in this study because of its local availability, brought from Al-Dourah refinery at Baghdad City. Table 1 illustrates the physical properties of this type of asphalt binder.

2.1.2 Coarse aggregate used

The coarse aggregate utilized in this study was crushed quartz brought from the most well-known sources in Baghdad City, Al-Nibaee quarry. This aggregate is commonly used in the production of conventional HMA in Baghdad city. The coarse aggregate gradation for wearing layer type AIII ranges from the maximum aggregate size (19mm), and nominal maximum size (12.5 mm) to sieve No.4 (4.75mm). The selection of gradation was adopted according to the requirement of SCRB specification (R/9) [11]. Various tests were conducted on the coarse aggregate to investigate their physical properties and chemical composition; the outcomes are shown in Tables 2 and 3, respectively.

Table 1. Physical properties of the Al-Dourah'AC (40-50).

Test	Unit	ASTM Designation	Test Result	SCRB Specification
Penetration 25°C,100 gm , 5 sec.	0.1 mm	D-5	45	40-50
Kinematics' Viscosity at 135C	C St.	D-2170	395	…….
Softening Point	C^o	D-36	52	……..
Ductility (25°C, 5 cm/min.)	cm	D-113	135	>100
Specific Gravity at 25°	…..	D-70	1.04	…….
Flash Point	C^o	D-92	295	> 232
Residue from thin-film oven test		D-1754		
- Retained penetration,% of original	0.1 mm	D-5	58	>55
- Ductility at(25 C, 5cm/min)	cm	D-113	52	>25

2.1.3 Fine aggregate

Crushed gravel and natural river sand are used as fine aggregate in this study. The fine part of the aggregate has been brought from the same source of coarse aggregate, Al-Nibaee quarry in Al- Taji. The fine aggregate gradation ranges from passing through sieve No.4 (4.75mm) to retain on sieve No.200 (0.075mm). The chemical composition and physical properties of the fine aggregate are shown in Tables 3 and 4, respectively.

Table 2. Physical properties of Al-Nibaee quarry coarse aggregate

Property	ASTM	Result	SCRB Specification
Bulk specific gravity (gm/cm^3)	C127	2.595	-
Apparent specific gravity (gm/cm^3)	C127	2.641	-
Percent water absorption (%)	C127	0.501	-
Percent wear (loss angels abrasion) (%)	C131	18.4	30% Max
Percent soundness (loss by sodium sulfate solution) (%)	C88	2.96	10% Max
Percent flat and elongated particles (%)	D4791	1.5	10% Max
Percent fractured pieces (%)	-	97	95% Min

Table 3. Chemical composition of Al-Nibaee quarry aggregate

Chemical Compound	Result %
Loss on Ignition (L.O.I)	6.5
Silica (SiO_2)	82.4
Lime (CaO)	5.56
Magnesia (MgO)	0.75
Sulfuric Anhydride (SO_3)	2.75
Ferric Oxide (Fe_2O_3)	0.7
Alumina (Al_2O_3)	0.5
Total	99.16
Mineral Composition	
Quartz	80.5
Calcite	10.9

Table 4. Physical properties of Al-Nibaee quarry fine aggregate

Property	ASTM	Result	SCRB Specification
Bulk specific gravity (gm/cm^3)	C128	2.642	-
Apparent specific gravity (gm/cm^3)	C128	2.685	-
Percent water absorption (%)	C128	0.688	-
Percent sand equivalent (%)	D2419	54	45% Min

2.1.4 Mineral filler

Two types of mineral filler passing sieve No.200 (0.075mm) have been used in this study. The first is Ordinary Portland cement Type (I) from Bazian Company in Iraq. It was kept in closed plastic containers to product protection from moisture exposure and other atmospheric conditions. The physical properties and chemical composition of Portland cement are shown in Tables 5 and 6, respectively.

The second filler type is the proposed material of this research, which is Metakaolin. It is obtained from kaolin clay collected from the Dewekhla region in the Al-Anbar governorate. The Kolin the and then burned in furnace up to 700 $^oC \pm 20$ ^oC for 1 hour [12]. After that, the Metakaolin is grinded to the specific surface area of 1900 m^2/kg. The physical properties and chemical composition of Metakaolin that adequate to the requirements Pozzolan ASTM C-618 are displayed in Tables 7, and 8, respectively. Table 9 shows the Comparison of the Chemical Composition of Metakaolin with ASTM Standard C-618.

Table 5. Physical properties of mineral filler (portland cement)

Property	Result
Specific gravity	3.11
Passing sieve No.200 (0.075mm)	94%
Surface area (m2/kg)	390

Table 6. Chemical composition of mineral filler (cement)

Chemical Composition	Result (%)
Loss on Ignition (L.O.I)	2.24
Silica (SiO_2)	21.77
Lime (CaO)	61.90
Magnesia (MgO)	3.91
Sulfuric Anhydride (SO_3)	2.50
Ferric Oxide (Fe_2O_3)	3.33
Alumina (Al_2O_3)	4.76
Insoluble material (I.R)	0.88
Lime saturation factor (L.S.F)	0.78

Table 7. Physical properties of mineral filler (metakaolin)

Property	Result
Specific gravity	3.15
Passing sieve No.200 (0.075mm)	95%
Surface area (m2/kg)	1900

Table 8. Chemical composition of mineral filler (metakaolin)

Chemical Composition	Result (%)
Loss on Ignition (L.O.I)	6.12
Silica (SiO_2)	51.59
Lime (CaO)	0.45
Magnesia (MgO)	0.23
Sulfuric Anhydride (SO_3)	0.14
Ferric Oxide (Fe_2O_3)	1.82
Alumina (Al_2O_3)	38.11
K_2O	0.43
Na_2O	0.11

Table 9. Comparison of chemical composition of metakaolin with ASTM standard C-618

Chemical Composition	Mineral Admixture Class			Test Result
	N	F	C	
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3) , min %	70	70	50	91.52
Sulfur trioxide (SO_3), max %	4	5	5	0.14
Loss on ignition, max %	10	6	6	6.12

As shown in Table 9, the chemical properties of the MK additives used in this research fit with chemical properties of mineral mixture class N. this means that according to the ASTM Standard C-618, the used filler has pozzolanic behavior which can be used to achieve the aim of this research.

2.2 Gradation of aggregate

In this study, the selected aggregate gradation follows the mid-point gradation to satisfy the SCRB (R/9) specification requirements of the hot mix asphalt paving mixture of the wearing layer [11]. The maximum aggregate size is (19mm), and the maximum size is (12.5mm). Table 10 presents the aggregate gradation of the wearing layer. Figure 1 displays the graphical presentation of specification limits and the mid-point particle size distribution of aggregate for the wearing layer.

Table 10. Aggregate gradation of wearing layer according to SCRB (R/9) specification

Sieve size	Sieve opening (mm)	Percentage passing by weight	
		SCRB limits	Mid-point
3/4	19	100	100
1/2	12.5	90-100	95
3/8	9.5	76-90	83
No.4	4.75	44-74	59
No.8	2.36	28-58	43
No.50	0.30	5-21	13
No.200	0.075	4-10	7

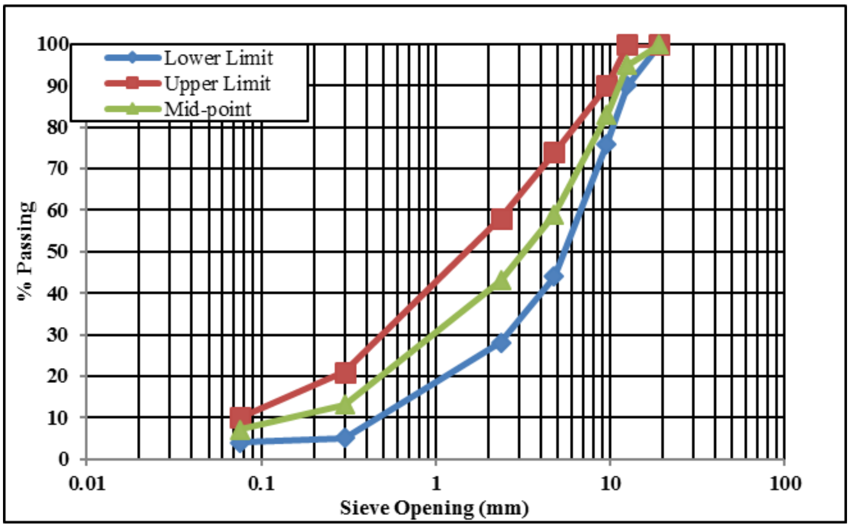

Figure 1. Specification limits and mid-point gradation of wearing layer

3. Experimental work

The experimental work of this study started with the preparation of five types of asphalt concrete mixtures according to Iraqi specification (SCRB R/9) [11]; each contains a different percentage of Metakaolin as a mineral filler replacement of cement. Then, the optimum asphalt content was determined using the Marshall Mixture design method. The asphalt concrete mixtures were then prepared at their optimum asphalt content and tested to evaluate temperature susceptibility and moisture damage trough the indirect tensile strength test and indirect strength ratio test.

3.1 Mix design method

Marshall mixture design method is used to prepare five mixtures with the various proportions of Metakaolin as mineral filler (0%, 25%, 50%, 75%, and 100%) replacement of cement according to Iraqi specification (SCRB R/9). Six sets of Marshall Specimens for each replacement proportion of Metakaolin were prepared with a constant increase ratio in asphalt content of 0.25% to determine the optimum asphalt content. The asphalt cement content used for each Metakaolin proportion starts at 4.25% at 0% of Metakaolin and increased by 0.25% for each replacement proportion.

Marshall specimens were set according to (ASTM Designation: D 1559), cylinder-shaped samples with a radius of 2 inches (50.8 mm), and a depth of 2.5 inches (63.5 mm). The mixing and compaction temperatures for asphalt mixtures should achieve a viscosity of (170±20) centistoke for mixing and (280±20) centistoke for compaction. The specimens were compacted with (75) blows/end with a hammer of 10 Ib , (4.536 kg), sliding weight, and a free fall of 18 inches (457.2 mm) on the top and bottom of each sample. The specimens were left at laboratory temperature for (24 hr).

Marshall Stability and flow also were determined for each specimen. To perform that, the specimen was put in a water bath at (60 ^oC) for 30 min. Then, it was compressed on the horizontal plane at a constant rate of 2in/min (50.8mm/min) to record the maximum load resistance and corresponding flow value. After that, the Bulk specific gravity of asphalt mixtures was determined according to (ASTM D-2726) test, while the (ASTM D-2041) test was used to determine the maximum theoretical specific gravity in the laboratory. Then, the volumetric properties of asphalt mixtures: air voids, voids filled with asphalt, and voids in mineral aggregate were calculated.

The average of three values of optimum asphalt content of maximum bulk specific gravity, maximum stability, and 4% air voids is used as the optimum asphalt content according to the limits of Iraqi specification (SCRB R/9, 2003) as shown in Table 12.

Table 12. Optimum asphalt content

Metakaolin Content, %	0	25	50	75	100
Optimum Asphalt Content, %	4.80	4.95	5.20	5.30	5.40

3.2 Indirect tensile strength (ITS) test

The ITS test has been adopted to examine the tensile properties of the HMA. The procedure described by (ASTM D-6931) was followed to determine the ITS and the resistance of the mixture to temperature variation. A set of cylindrical specimens for each mixture was prepared by Marshall Procedure (ASTM D-1559). Three testing temperature has been selected, 25, 40, and 60 ^oC to evaluate temperature susceptibility. The set consists of nine cylindrical specimens three for each testing temperature. In this test, the vertical compressive load was subjected to the center of the vertical circular plane of the specimen at the rate of 2 in/min (50.8 mm/min). The maximum load resistance was recorded. Equation 1 was used to calculate the ITS while Equation 2 was used to calculate the temperature susceptibility [13].

$$ITS = \frac{2*P}{\pi*D*T} \qquad (1)$$

Where :

ITS = Indirect Tensile Strength (kPa),
P = Maximum load resistance (kN),
T = Thickness of Specimen (mm), and
D = Diameter of Specimen(mm).

$$TS = \frac{(ITS)_{t1}-(ITS)_{t2}}{t_2-t_1} \qquad (2)$$

Where :
TS = Temperature Susceptibility (kPa/^{o}C),
$(ITS)_{t1}$ = Indirect Tensile Strength at t_1= 25 ^oC, and
$(ITS)_{t2}$ = Indirect Tensile Strength at t_2= 40 ^oC.

3.3 Moisture damage (MD) test

Moisture damage affects the performance and durability of HMA. The MD test is used to examine water susceptibility of HMA by determining the difference in stiffness value before and after conditioning in water. The procedure of (ASTM D-4867) was adopted to measure the water sensitivity. The results represent the conditioned and unconditioned ITS and the indirect tensile ratio.

Marshall procedure (ASTM D-1559) was followed to prepare a set of six specimens for each mixture. These specimens were compacted to get 7±1 % air voids. Three unconditioned specimens, control, were tested at 25°C. The others are conditioned and were subjected to one cycle of freezing and thawing then tested at 25°C.

The ISR was calculated using Equation 3.

$$ISR = \frac{ITS_c}{ITS_d} \qquad (3)$$

Where:
ISR = Indirect Tensile Strength Ratio (%),
ITS_c = Indirect Tensile Strength of conditioned specimens (kPa), and
ITS_d = Indirect Tensile Strength of unconditioned specimens (kPa).

4. Results discussion

4.1 Effects of metakaolin on marshall properties

The variance in Marshall properties at different percentages of Metakaolin content has been presented in Figures 2-7. The results presented in Figure 2 indicate that the optimum asphalt content grows as the percent of Metakaolin increases, the mixture with 100 percent of Metakaolin possess the highest optimum asphalt content of (5.4%) while the lowest value of (4.8%) was obtained at control mixture with zero percent of Metakaolin (the mineral filler entirely consists of cement). These results can be assigned based on the surface area of Metakaolin comparing to the surface area of cement. As presented in the physical properties of the filler, the surface area of Metakaolin is about 4.87 times that of cement, so the asphalt content requirement has grown as the replacement rate of Metakaolin increased.

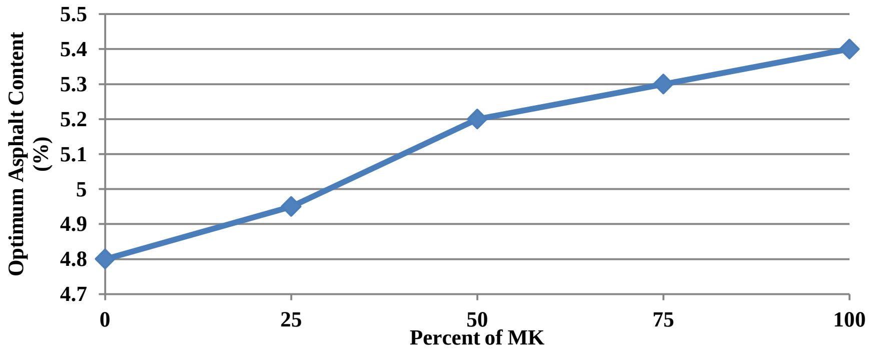

Figure 2. Optimum asphalt content at varying metakaolin content

The results of the Marshall Stability are presented in Figure 3. They indicate that stability grows with the growth of Metakaolin content. The growing rate varies with the Metakaolin content. At 25% of Metakaolin, the increasing rate gained is 4.74%, while the maximum rate gained is 13.39% at 50% of the Metakaolin content. After that, the growth rate decreased, the 75 and 100 percent of Metakaolin produced 14.4%, 15.22% at their optimum asphalt content. From these results, it may be possible to propose that the 50 percent of Metakaolin gives the highest stability since a further increase in the Metakaolin content produce less increasing rate instability value and require higher asphalt content as compared to the mixture with the 50% of Metakaolin.

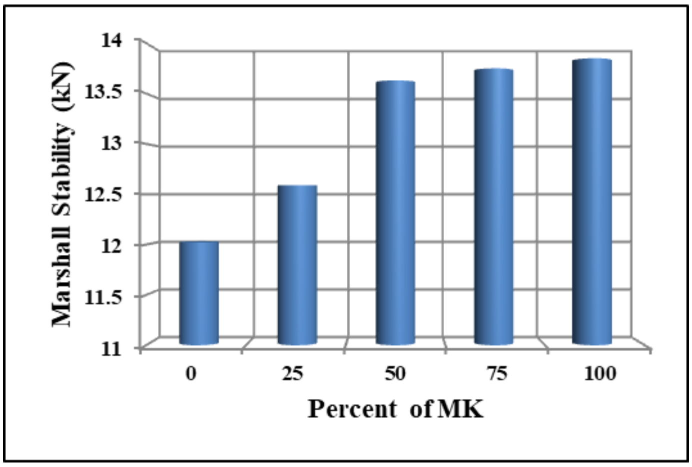

Figure 3. Marshall Stability at varying metakaolin content

Figure 4 presents the results of Marshall Flow as a function of the Metakaolin content. It shows that the value of Marshall Flow grows as the Metakaolin content grows until 50 percent; then, the value starts to decrease at 75 and 100 percent. The reason is that the air voids decrease as the Metakaolin content increases to reach the lowest value at 50 percent. Adding more Metakaolin leads to raising in air voids so the flow value decline.

Figure 5 shows the change in the Marshall density at different replacement percentage of Metakaolin content. The results illustrate that the Marshall Density increases with the increase in the Metakaolin content until it reaches its highest value at 50% of Metakaolin content with (1.03%) rate of increase. Then, the bulk density decreases with further additions. However, the Marshall Density for all mixtures with different percentages of Metakaolin is higher than that of the control mixture because of the fineness property of Metakaolin particles, which produces denser HMA.

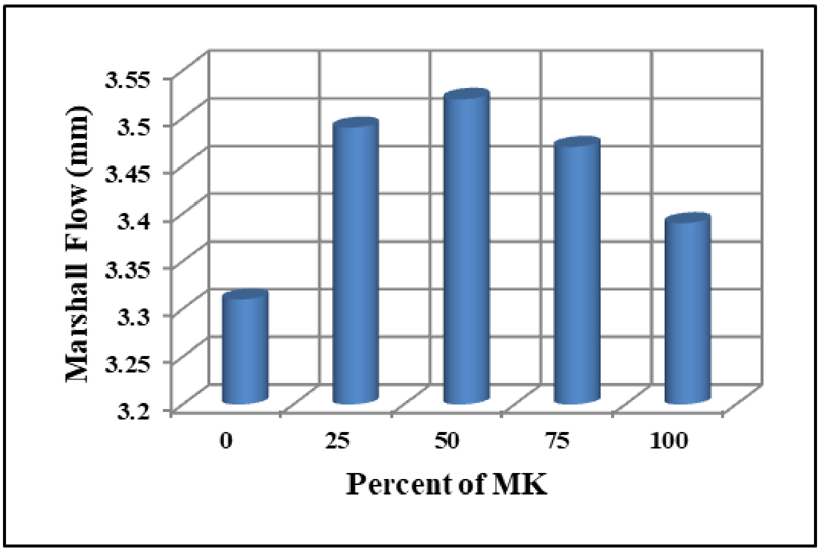

Figure 4. Marshall flow at varying metakaolin content

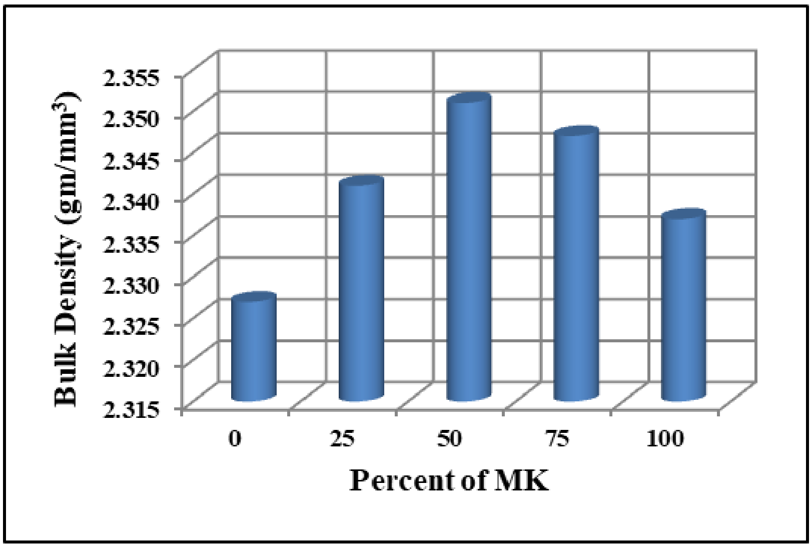

Figure 5. Marshall density at varying metakaolin content

The relationship between the air voids and the replacement percentages of Metakaolin content at optimum asphalt content, which illustrated in Figure 6, supports the relationship observed between Metakaolin content and flow. The air voids decrease with increasing the Metakaolin content to the lowest value at 50 percent of Metakaolin at the rate of (-5.1%) then the air voids grow as the Metakaolin content grows at the rate of (-0.97%) and (+3.88%) at 75 and 100 percent respectively. The reason is that the very fine Metakaolin particle filled the voids of the HMA more efficiently than cement filler, and then stiffens the mixture at an optimum percentage of Metakaolin. Any addition beyond the 5o% of the Metakaolin filler will affect the density of the mix, which will result in lacking the compaction effort and increasing in the air voids content.

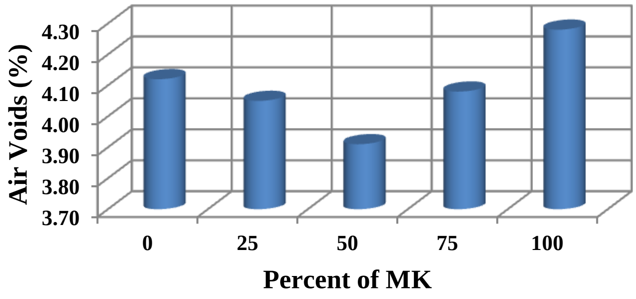

Figure 6. Air voids at varying metakaolin content

From the investigation of the results presented in Figure 7, it can be concluded that the voids in mineral aggregate (VMA) decreases as the Metakaolin content increases by up to 50%. The minimum value of (VMA) corresponding to 50% of Metakaolin is (16.39%) with decreasing rate (-1.82%). This means that fewer voids accommodated by asphalt cement. After 50% of Metakaolin content, adding more of the Metakaolin filler results in growing the VMA values.

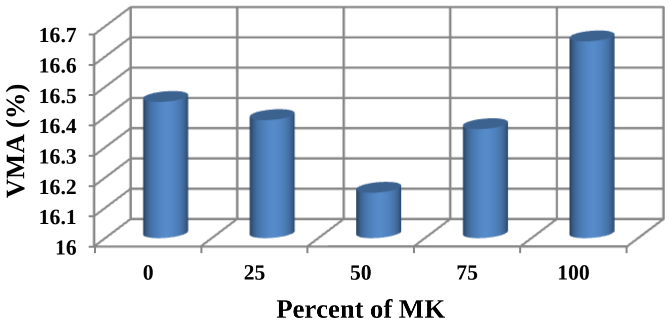

Figure 7. Voids in mineral aggregate at varying metakaolin content

4.2 Effects of metakaolin on ITS and temperature susceptibility

Figure 8 illustrates the change in the ITS resulted from increases in the Metakaolin content at three degrees of temperature; 25, 40, and 60 ^{o}C. It can be concluded that the ITS increases continuously as the Metakaolin content increases at the same reference temperature, but it declines as temperature increases. At 25 ^{o}C the ITS increase rate is more pronounced at 25% and 50% of Metakaolin content about (5%) and (9.3%), respectively, then become less pronounced at 75% and 100% about (10.3%) and (11.7%), respectively. At 40 ^{o}C the increases rate in ITS value is more than the rate at 25 ^{o}C about (13.5%), (31.5%), (37.4%), and (42.5%) at 25, 50, 75, and 100% of Metakaolin content respectively. The ITS increase rate is more noticeable with the increase in Metakaolin content at 60^{o}C to become (20.5%), (56%), (64%), and (69%) at 25, 50, 75, and 100%.

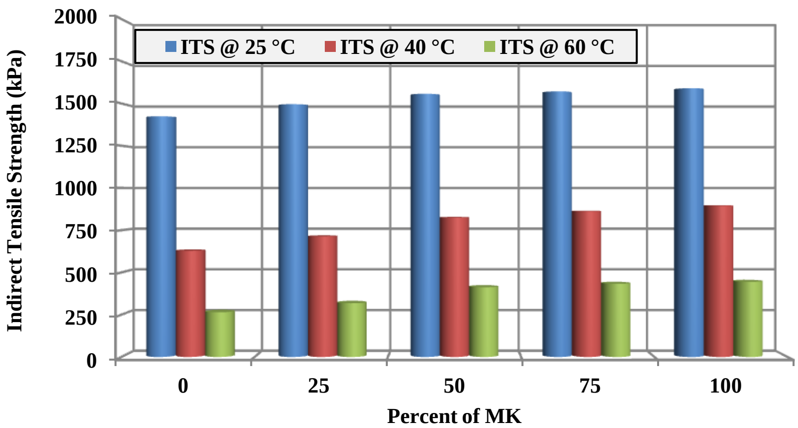

Figure 8. Effect of metakaolin content on the ITS at different temperature

Temperature susceptibility (TS) for each mixture is illustrated in Figure 9. The TS is obtained from the result of the ITS test at 25°C and 40°C. It proposed that the temperature susceptibility decreases as the Metakaolin content increases. The Metakaolin content of 25, 50, 75, and 100% produced rates of reduction in the temperature of about 1.67%, 7.98%, 10.85%, and 12.63%, respectively. This means the changeless influences mixtures that contain Metakaolin filler in temperature than the control mixture.

Temperature susceptibility (TS) for each mixture is illustrated in Figure 9. The TS is obtained from the result of the ITS test at 25°C and 40°C. It proposed that the temperature susceptibility decreases as the Metakaolin content increases. The Metakaolin content of 25, 50, 75, and 100% produced rates of reduction in the temperature of about 1.67%, 7.98%, 10.85%, and 12.63%, respectively. This means the changeless influences mixtures that contain Metakaolin filler in temperature than the control mixture.

4.2 Effects of metakaolin on moisture susceptibility

Two types of results obtained from the moisture damage test, the first is the ITS for conditioned and unconditioned specimens, and the second is the ISR. According to Figure 10 that illustrates the changes in the ITS with the changes in the Metakaolin content for both conditioned and unconditioned specimens, it can be seen that the ITS value increases approximately linearly with increasing the Metakaolin content. It also observed that the increase rate in the conditioned ITS is higher than ITS in the case of unconditioned. For example, at 25% of Metakaolin content, the improvement rate in conditioned ITS is 20.9%, while the improvement rate in unconditioned ITS is 14.7%. The finding shown in Figure 11 illustrates the increase in the ISR as the percentage of Metakaolin content increases. These results demonstrate that the resistance of the modified HMA to moisture damage improved with adding Metakaolin filler.

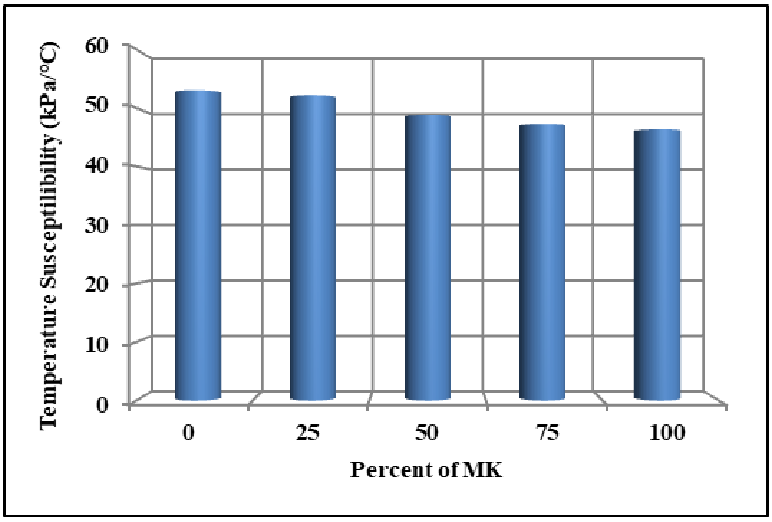

Figure 9. Effect of metakaolin content on the temperature susceptibility

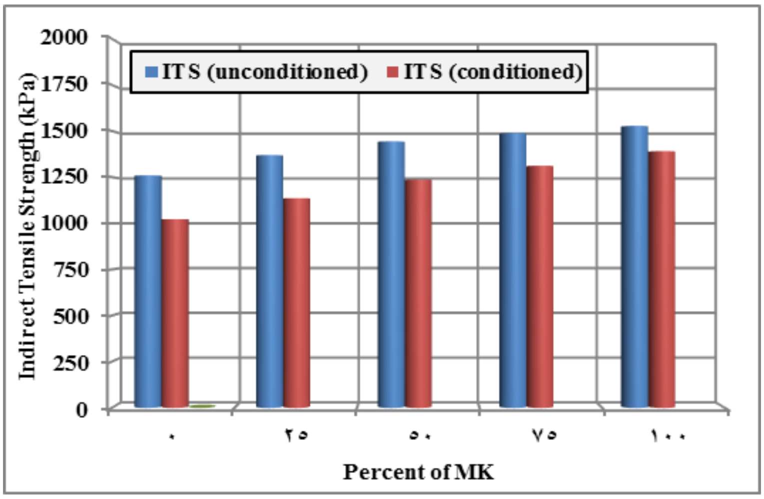

Figure 10. Effect of metakaolin content on the conditioned and unconditioned ITS

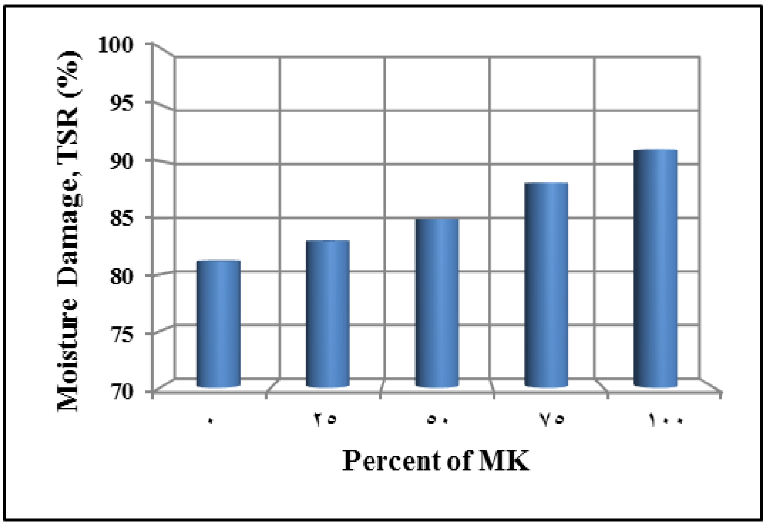

Figure 11. Effect of metakaolin content on the indirect tensile strength ratio

5. Conclusions

According to the results and the analysis of the laboratory tests illustrated in this study, it can be concluded that:

1. Metakaolin used in this study is adequate to Pozzolan requirements of ASTM C618, class N, and can be used as a mineral filler in the HMA as a partial replacement of cement.
2. The addition of different proportions of Metakaolin filler as replacement of cement has a significant influence on the mechanical properties of the HMA. These result can be summarized as follow:
   - The optimum asphalt content grows as the percent of Metakaolin increases. The mixture with 100% of Metakaolin possesses the highest optimum asphalt content of 5.4% while the lowest value of 4.8% obtained at a control mixture with 0% of Metakaolin.
   - Marshall Stability grows with the growth of Metakaolin content. The growing rate is different for each Metakaolin content; the maximum growing rate gained is 13.39% at 50% of the Metakaolin content.
   - The value of Marshall Flow grows as the Metakaolin content grows to 50%, and then the value starts to decrease at 75 and 100% due to the insufficient compaction effort.
   - Marshall density values increase up to peak point at 50% of Metakaolin content with a 1.03% rate of increase and then decrease with further additions.
   - Air voids decrease with increasing the Metakaolin content to the lowest value at 50 percent of Metakaolin at the rate of -5.1%, and then the air voids grow as the Metakaolin content grows.
   - Voids in mineral aggregate (VMA) decrease with increasing Metakaolin content up to 50%, and any addition of Metakaolin results in increasing the VMA values. The minimum value of (VMA) corresponding to 50% Metakaolin is 16.39%.
3. The indirect tensile strength increases continuously as the Metakaolin content increases at the same reference temperature, but the indirect tensile strength decreases as temperature increases. The ITS increase rate is more noticeable at 40 ^{o}C and 60 ^{o}C than that at 25 ^{o}C.
4. Temperature susceptibility decreases as Metakaolin content increases, the mixtures contain Metakaolin as mineral filler is insignificantly affected by temperature change comparing to the control mixture.
5. The improvement rate in the ITS of the conditioned samples is higher than ITS improvement in the case of unconditioned. This demonstrates the enhancement of the modified HMA's resistance to moisture damage.
6. The Marshall properties, temperature and moisture susceptibility of hot asphalt mixture can b**e** modified by using Metakaolin as a partial replacement mineral filler at 50% and optimum asphalt content of 5.2%.

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References

[1] S. O.E., "The influence of Filler Type on Asphalt Mastic and Performance Properties of Asphalt Paving Materials," M.Sc. Thesis, Civil Engineering, University of Anbar, University of Anbar, 2010.

[2] F. Wagaw, E. T. Quezon, and A. Geremew, "Evaluation of the Performance of Brick Dust as a Filler Material for Hot Asphalt Mix Design: A Case Study in Jimma Zone," *The International Journal of Engineering and Science (IJES),* vol. 7, no. 3, pp. 64-72, 2018.

[3] H. H. Jony, I. Y. Jahad, and M. F. Al-Rubaie, "The effect of using glass powder filler on hot asphalt concrete mixtures properties," *Engineering and Technology Journal,* vol. 29, no. 1, pp. 44-57, 2011.

[4] A. F. Al.ani, "Effect of Fly-ash on The Performance of Asphalt Concrete Mixes," *Journal of Babylon University/Engineering Sciences,* vol. 25, no. 5, 2017.

[5] N. AH AL-Saffar, "The effect of filler type and content on hot asphalt concrete mixtures properties," *AL-Rafdain Engineering Journal,* vol. 21, no. 6, pp. 88-100, 2013.

[6] M. Karaşahin and S. Terzi, "Evaluation of marble waste dust in the mixture of asphaltic concrete," *Construction and Building Materials,* vol. 21, no. 3, pp. 616-620, 2007.

[7] V. A. Varma and M. T. S. Lakshmayya, "A review on different types of wastes used as fillers in bituminous mix," *International Journal of Civil Engineering and Technology,* vol. 9, no. 9, pp. 289-300, 2018.

[8] H. H. Murray, "Traditional and new applications for kaolin, smectite, and palygorskite: a general overview," *Applied Clay Science,* vol. 17, no. 5-6, pp. 207-221, 2000.

[9] A. Murana, A. Olowosulu, and S. Ahiwa, "Performance of metakaolin as partial replacement of cement in hot mix asphalt," *Nigerian Journal of Technology,* vol. 33, no. 3, pp. 387-393, 2014.

[10] M. M. Satar, R. Jaya, M. Rafsanjani, N. CheMat, M. Hainin, M. M. Aziz, M. Abdullah, and D. Jayanti, "Performance of Kaolin Clay on Hot-mix Asphalt Properties," in *Journal of Physics: Conference Series*, 2018, vol. 1049, no. 1, p. 012002: IOP Publishing.

[11] *SCRB, General Specification for Roads and Bridges, Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition*, 2003.

[12] *ASTM, C 618: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Portland Cement Concrete*, 2002.

[13] H. Ab., "Evaluation of Suitable Temperature Susceptibility Index for Local Paving Asphalts," M.Sc. Thesis, Civil Engineering, University of Baghdad, Republic of Iraq, 1999.