Study the Effect of Mineral Filler on the Mechanical Properties of Hot Mix Asphalt

Eman Abdul Al-Hasan Mohammed¹  Safaa A Mohamad¹  Teba Tariq Khaled¹ ²
Ayar Alzubaidi²

¹ Assistant Lecturer, Highway and Transportation Engineering Department, College of Engineering, Al-Mustansiriyah University, Baghdad, Iraq.
² Dr. at Department of Life Science and Applied Chemistry Nagoya Institute of Technology Gokiso-Cho-Showa-Ku- Nagoya- Aichi, 466-8555 Japan.

*Corresponding author: E-mail address teba.tariq@uomustansiriyah.edu.iq
Or teba.t.khaled@gmail.com

Abstract: The important component in the asphalt mixture is mineral filler materials as it plays an essential part in the stiffening and toughening of asphalt binder. In addition, the mechanical properties of asphalt binder are influenced by the mineral filler, and significantly affected with respect to stripping or moisture susceptibility. This paper is displayed the mechanical properties of asphalt mixtures that used asphalt binder grade (40-50), the gradation of aggregates selected with the mid-point according to the Iraqi specification and two types of mineral filler materials (High Reactivity Attapulgite (HRA) and Portland Cement (PC)) according to the empirical requirements. The mixtures are produced and compacted according to the Marshall Mix design method. In addition, this paper is displayed the positive influence of HRA and PC in the asphalt mixtures such as (Volumetric Properties, Marshall Properties, Marshall Stiffness, the Indirect Tensile Strength and Moisture Susceptibility). The results explained that the (5%) and (7%) HRA had an important influence on the properties of asphalt mixtures. With the increment in the percentages of HRA, the volumetric properties of asphalt mixtures enhanced. Laboratory investigations results support the advantage of adding HRA to the asphalt mixtures. HRA as an active mineral filler has good resistance to moisture sensitivity and mechanical properties, which contributes to extending the life cycle of the pavement layer.

Keywords: Hot Mix Asphalt (HMA), Mineral Fillers, High Reactivity Attapulgite (HRA), Portland Cement (PC), and Moisture Susceptibility.

1. Introduction
A mineral filler is a fraction of inert mineral dust with particle size less than 75µ and used in the asphalt mixture. It was used to fill the air-voids in the coarse and fine aggregates, and that led to improving the density, stability, and toughness of a traditional asphalt mixture [1]. Therefore, the mineral filler has a notable influence in the conventional mixtures. In addition, the excess amount of mineral filler leads to increase stability, brittleness, and ability to cracking. Nevertheless, When the mineral filler particles are severally coated with thin films of asphalt, strong, stable, tough mixes can be prepared composed of (100%) mineral filler with (20% to 25%) of asphalt. In the up-to-date years, numerous countries have experienced an increment in vehicle tire pressures, axle-loads and traffic volumes. If the vehicle tire pressure and axle-load increments, then the top layer of the asphaltic surface is subjected to higher stress [2]. The high traffic volumes in the terms of commercial vehicles, overloading of trucks and notable differences in daily and seasonal temperature of asphalt pavements layer, which have been associated with the development of deformations such as; ravelling, undulations, rutting, cracking, bleeding, shoving and potholing of asphalt pavement surfaces [2]. The combinations of good materials with asphalt binder, which have been led to an increase in the service life of asphaltic pavement depending upon the aggregates, applied [3]. The good type of mineral filler aggregate is drained because of large-scale pavement infrastructure projects in Iraq. Therefore, there are different types of mineral filler materials can be applied in the pavement construction such as Portland cement (PC), hydrated lime, limestone dust, fly ash and high reactivity attapulgite (HRA) etc. In addition, the researchers recommended being studied the laboratory, field performance, and conducted out to verify the suitability of these materials in pavement construction. Al-Amide and Malik investigated a new type of Iraqi...
attapulgite clays as high reactivity pozzolanic [4]. Al-Amide and Malik carried tests out to determine the most suitable calcination temperature and time to produce high activity attapulgite. The results showed that the optimum calculation temperature to convert the attapulgite clay to high reactivity attapulgite is 750 °C and that the optimum calcination time is (30 min) [4].

2. Materials and Experimental Method

Figure 1 displays the detailed of the experimental design followed in this study which involved one grade of asphalt cement used in prepared asphalt mixture and obtained from Daurah refinery and table 1 are presented the physical properties of the asphalt cement. Concerning the gradation of the aggregate, which consisted of the coarse aggregates, fine aggregates and mineral filler. The size of coarse aggregate is ranged from sieve (19.0 mm) to sieve (4.75 mm), in addition, the size of fine aggregate is ranged from sieve (2.36) to sieve (0.075) sieve. Tables 2 and 3 displays the physical properties and chemical composition of the coarse and fine aggregates. Therefore, the aggregates gradation followed the mid-point gradation to achieve the limits of Iraq specification requirements [5]. However, the aggregates gradation are one of the essential properties to meet the volumetric properties, Marshall-stability and Marshall-flow of the asphaltic mixtures. The aggregates gradation chosen to prepare the asphalt mixtures are illustrated in figure 2 according to Iraqi specification [5].

It should be noted that the mineral filler used in this study was high reactivity attapulgite (HRA) and obtained the attapulgite clays from tar in Al-Najaf (Anjana) reign as shown in figure 3 and Portland cement (PC). The attapulgite turns to active pozzolanic material when it burns to certain temperature (750 °C) for (30 min) about (4 °C/min). Then the materials are cooled down by opening the oven door slightly to allow heat exchange with the ambient temperature to the next day. Tables 4 and 5 show the chemical and physical properties of (HRA) [6].
Table 1. Physical Properties of Asphalt Cement \(^1\) [7]

| Test                      | ASTM Designation | Asphalt Results | SORB Limits |
|---------------------------|------------------|-----------------|-------------|
| Penetration               | ASTM D5          | 45              | 40-50       |
| Ductility                 | ASTM D 113       | >100            | ≥100        |
| Softening point           | ASTM D 36        | 52              | 50-60       |
| Flash point               | ASTM D92         | 328             | ≥240        |
| **After Thin-Film Oven Test (ASTM D-1754)** |                  |                 |             |
| Penetration of Residue    | ASTM D 1754      | 33              |             |
| Ductility of Residue      | ASTM D 113       | >100            | >100        |
| Loss in weight            | ASTM D 1754      | 0.18            | ≤0.75       |

Table 2. Physical Properties of Nibaee Aggregates\(^1\) [7]

| Property                                      | Coarse Aggregate | Fine Aggregate |
|-----------------------------------------------|------------------|----------------|
| Bulk Specific Gravity (ASTM C127 and C128).  | 2.610            | 2.631          |
| Apparent Specific Gravity (ASTM C127 and C128). | 2.641            | 2.6802         |
| Percent Water Absorption (ASTM C127 and C128). | 0.423            | 0.542          |
| Percent Wear (Los-Angeles Abrasion) (ASTM C131) | 20.10            | ……             |

Table 3. Chemical Composition of Nibaee Aggregates\(^1\)

| Chemical Compound       | % Content |
|-------------------------|-----------|
| Silica SiO2             | 82.52     |
| Lime CaO                | 5.37      |
| Magnesia MgO            | 0.78      |
| Sulfuric Anhydride SO3  | 2.7       |
| Alumina Al2O3           | 0.48      |
| Ferric Oxide Fe2O3      | 0.69      |
| Loss on Ignition        | 6.55      |
| Total                   | 99.09     |

| Mineral Composition     |          |
|-------------------------|----------|
| Quartz                  | 80.3     |
| Calcite                 | 10.92    |

Figure 2. Specification Limits and Gradation for Wearing Layer [5]

\(^1\) The test was done in cooperation with National Centre for Construction Laboratories and Research.
3. Plans and Goals

1. This study focuses on produce asphalt mixtures by using different types and percentages from the unconventional mineral-filler materials (High Reactivity Attapulgite) and conventional mineral-filler materials (Portland cement).

2. Study the volumetric properties, mechanical characteristics, and resistance to moisture susceptibility for the mixtures with unconventional mineral-filler materials (High Reactivity Attapulgite) and conventional mineral-filler materials (Portland cement).

3. The comparison between the volumetric properties, mechanical characteristics, and resistance to moisture susceptibility for the mixtures with unconventional mineral-filler materials (High Reactivity Attapulgite) and conventional mineral-filler materials (Portland cement).

4. Marshall Mix Design

The purpose of the design hot mix asphalt was to find the optimum asphalt binder content and prepare a mixture with suitable performance and good mechanical properties, Marshall properties, and resistance to moisture susceptibility. Further, the mix design should be achieved the volumetric characteristics demanded such as air-voids (Va), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA) [3][9]. The asphaltic mixtures were designed by utilizing the Marshall-method, and aggregates gradation adopted on the Iraqi specifications requirement [5]. Therefore, the Marshall-design method...
procedure was used to determine the optimal asphalt binder content for the control mixture and mixtures with different types and percentages of mineral filler, regarding the mixture test results for Marshall stability and flow, also the volumetric values: Va, VMA and VFA [3] were showed in table 8. The optimum content of asphalt binder for the HMA in control mixture was (5%); that was used to determine the Marshall properties of control and mixtures with different types and content of mineral filler as shown in figure 4 [3]. Therefore, this study was focus on the volumetric properties, mechanical characteristics and performance of asphalt mixtures which used different percentages from mineral filler HRA and compared with reference mixture that was prepared from mineral filler PC. The reference mixtures used in this study were mixtures a prepared with different percentages of conventional mineral-filler materials (Portland cement) which utilized to compare with mixtures a prepared with the same percentage above, but by using unconventional mineral-filler materials (High Reactivity Attapulgite). The different percentages of conventional mineral-filler materials (Portland cement) and unconventional mineral-filler materials (High Reactivity Attapulgite) used in this study are (5%, 7%, and 9%) based on the Iraq specification requirements for the mineral-filler materials [5].

5. Indirect Tensile Strength

The indirect tensile strength test is one of the significant importance property in the asphaltic mixtures design and utilised to estimate the tensile characteristics of the asphaltic mixtures, which can be associated with the cracking properties of the asphaltic pavements. The indirect tensile strength specimens were prepared with Marshall-method accordance to ASTM [3] and the specimens with dimension (101.6mm) diameter and around (63.5mm) height [3]. The specimens after the preparation should be stayed to cool at the room temperature about (24hr.). Hence, the specimens were put in the water-bath for a (30min) at (25ºC) and the specimens were tested in the master loader device at the constant load-rate (50.8 mm/min), and the failure-load is recorded as shown in table 6. Therefore, the failure-load was used to calculate the ITS according to ASTM [10] by applying equation 1 [10].

\[
ITS = \frac{2000P}{\pi DT}
\]  

Where:

\( ITS \) = Indirect Tensile Strength, kPa  
\( P \) = Maximum load resistance at failure, N  
\( D \) = Diameter of specimen, mm  
\( T \) = Thickness of specimen immediately before test, mm

| Items                        | Range               | Applied       |
|------------------------------|---------------------|---------------|
| Number of Required Specimens | 3                   | 3             |
| Rate of Load Applied (mm/min)| 50±2                | 50.8 mm/min   |
| Measuring Device Accuracy    | ±0.2                | 0.2           |
| Test Temperature (°C)        | (5-25)±2            | 25°C          |
| Time for Storage in the Water-Path (min) | (30–45) | 30 min       |
6. Moisture Susceptibility

The susceptibility of moisture damage is a major factor that affected on the strength and durability of asphaltic pavements and can be considered as a deterioration of the mechanical properties for the paving’s and due to the influence of moisture or water, which can to serious distresses. Therefore, the failure of adhesion among the asphalt and aggregate and lack of cohesion inside the asphalt essentially due to the presence of water is commonly led to moisture susceptibility [11]. The ITS test is usually applied to assess the potential of moisture susceptibility of asphalt mixture. To find the ITS of asphalt mixtures, a Marshall specimens are prepared according to ASTM [3] and the specimens with dimension (101.6mm) diameter and around (63.5mm) height. Six specimens were prepared for each type of mixtures and these specimens divided into two groups (three replicate specimens) [11]. The first group was put in the water-bath at (25°C) about (30 min), it is represented ITS un-conditioned value. The second group was stored in the water-bath at (60°C) about (24hr.) and removed and put it in the other water-bath at (25°C) about (1hr), it is represented ITS conditioned value. Both groups are tested in the master loader device at the constant load-rate (50.8 mm/min), and the failure-load is recorded, the failure-load was used to calculate the ITS according to ASTM [10] as shown in figure 5 and table 7. The moisture susceptibility in the asphalt mixtures are represented as a ratio of the ITS conditioned value to the ITS un-conditioned value according to ASTM [11] as shown below.

\[
\text{Moisture Susceptibility} = \frac{\text{ITS conditioned value}}{\text{ITS un-conditioned value}} \times 100
\]

Figure 5. Samples Subject to ITS Test

Table 7. Test Conditions for Moisture Susceptibility According to ASTM [11]

| Items                          | Range Applied          | Applied        |
|--------------------------------|------------------------|----------------|
| Number of Required Specimens   | 3                      | 3              |
| Rate of Load Applied (mm/min)  | 50±2                   | 50.8 mm/min    |
| Measuring Device Accuracy      | ±0.2                   | 0.2            |
| **ITS for un-conditioned Specimens** |                        |                |
| Test Temperature (°C)          | (5-25)±2               | 25°C           |
| Time for Storage in the Water-Path (min) | (30-45)               | 30 min         |
| **ITS for conditioned Specimens** |                        |                |
| Test Temperature (°C)          | (60±5) and then (25±2) | 60°C and then 25°C |
| Time for Storage in the Water-Path (hr.) | For 60°C               | 24 hr.         |
|                                | For 25°C               | 1 hr.          |

7. Tests Results and Discussions

7.1. Volumetric Properties Analysis

The types of mineral-filler and content significantly influence on the volumetric properties of asphalt mixture. However, to determine the influence of unconventional mineral-filler materials (High Reactivity Attapulgite) and conventional mineral-filler materials (Portland cement) on the volumetric properties of asphalt mixture, the volumetric properties were studied at different percentages of mineral-filler content separately as displayed in table 8. The investigation results appear that the bulk density of
asphalt mixtures with the inclusion of mineral-filler materials (High Reactivity Attapulgite) gives a lower value than the conventional mineral-filler materials (Portland cement). In addition, the total air-voids in the mixture (Va) and voids in mineral aggregate (VMA) are more significant when the mineral-filler materials (Portland cement) was used as a filler in the asphalt-mixture. The applied of mineral-filler materials (High Reactivity Attapulgite) in the asphalt mixtures appear no significant effect in the value of voids filled with asphalt (VFA), maybe because of the lightweight of (High Reactivity Attapulgite) that was used to produce the asphalt mixture.

| Properties | Portland Cement (PC) | High Reactivity Attapulgite (HRA) |
|------------|----------------------|-----------------------------------|
| Density    | 2.31                 | 2.18                              |
| Va (%)     | 4.42                 | 4.33                              |
| VMA (%)    | 17.53                | 19.84                             |
| VFA (%)    | 78.80                | 72.31                             |

7.2. Marshall Properties Analysis

The used of unconventional mineral-filler materials with High Reactivity Attapulgite has a large impact on the Marshall Stability and Marshall Flow values for the asphaltic mixtures as displayed in figure 6 and 7. In the experimental program, the unconventional mineral-filler materials (High Reactivity Attapulgite) appears higher stability than the conventional mineral-filler materials (Portland cement). Nevertheless, all kinds of the mixtures with conventional and unconventional mineral-filler materials have the stability that was higher than the specified limit recommended by the Iraqi specification [5]. It can be noted that the flow value for the asphalt mixtures with the unconventional mineral-filler materials (High Reactivity Attapulgite) provides a lower value than the conventional mineral-filler materials (Portland cement). The HRA is good to be applied in the preparation of the asphaltic mixture, maybe because the HRA that was used in production the asphalt mixtures was a lightweight and finer material, which led to raising the viscosity of asphalt binder all this can improve the stability and reduce the fluidity.

7.3. Marshall Stiffness Analysis

The termed of Marshall-stiffness is represented as a ratio of the maximum Marshall-stability value to the corresponding Marshall-flow value at the optimum asphalt content that described the combination of Marshall-stability and Marshall-flow in the single value. Marshall-stiffness provides an indication about the resistance of asphaltic mixture to plastic flow, which was occurred due to traffic loading [12]. The higher values of Marshall-stiffness were evidence of significant resistance to permanent deformation for the asphalt mixtures that will be utilized in the pavement construction. In this study, it is noticed that the unconventional mineral-filler materials (High Reactivity Attapulgite) give a higher resistance to plastic flow of the mixtures than the conventional mineral-filler materials (Portland cement).
cement). Maybe because the HRA that was used in production the asphalt mixtures was a lightweight and finer material, which led to raising the viscosity of asphalt binder all this can improve the stiffness of asphalt mixtures. The unconventional mineral-filler materials (High Reactivity Attapulgite) in the mixture MF1 provided the higher value of Marshall-stiffness than conventional mineral-filler materials (Portland cement) at the same condition, but in the other mixtures, there is no significant effect in the Marshall-stiffness. The Marshall-stiffness for the various kinds of mineral filler materials is displayed in figure 8.

Figure 8. Effect of Mineral-Filler Types on the Marshall Stiffness

7.4. Indirect Tensile Strength Analysis
The indirect tensile test (ITS) was utilized to find the tensile properties for the cylindrical asphalt mixture by applying the compressive-loads on the specimen in the two opposite side. Therefore, the results can be adopted to determine the strength and quality of mixture materials applied in pavement construction. In this study, it is remarked that the ITS for the unconventional mineral-filler materials (High Reactivity Attapulgite) was lower than the conventional mineral-filler materials (Portland cement) in dry and wet condition. maybe because the HRA that was used in production the asphalt mixtures was a lightweight and finer material which led to raising the viscosity of asphalt binder all this can increase in the stiffness of the mixtures and reduce the ITS in dry and wet specimens. However, the ITS values of dry specimens for the unconventional mineral-filler materials (High Reactivity Attapulgite) and the conventional mineral-filler materials (Portland cement) more than the ITS values of wet specimens as presented in the figure 9 and 10.

Figure 9. Effect of Mineral-Filler Types on the ITS at Dry Specimens
Figure 10. Effect of Mineral-Filler Types on the ITS at Wet Specimens

7.5. Moisture Susceptibility Analysis
The worst enemy for the asphalt pavement is presence the water and that maybe led to early failure occurred in the flexible pavement [13]. The moisture susceptibility was determined by calculating the indirect tensile strength ratio (TSR) according to ASTM D4123 as explained in article 6 [11]. The moisture susceptibility for the various types of mineral-filler materials is presented in figure 11. In this investigation, it can be seen that the unconventional mineral-filler materials (High Reactivity Attapulgite) exhibit a lower value to resist the water damage than the conventional mineral-filler materials (Portland cement) except the mixture MF2 is the opposite. However, all the moisture susceptibility values for both unconventional mineral-filler materials (High Reactivity Attapulgite) and conventional mineral-filler materials (Portland cement) satisfy with the Iraqi specification requirement, which is (70%) [11]. Because the HRA that was used in production the asphalt mixtures was a lightweight and finer material, which led to raising the viscosity of asphalt binder all this can provide a good bond among the asphalt and aggregate. Finally, a good bond led to decreasing water absorption and improved the resistance to moisture susceptibility.

Figure 11. Effect of Mineral-Filler Types on the Moisture Susceptibility

8. Conclusions
Based on the investigation study results for the asphalt mixtures, which contain different types and percentages of mineral-filler materials, the following results can be drawn:

1. The volumetric properties and mechanical characteristics of the asphalt mixtures, which prepared with different types and percentages from the unconventional mineral-filler materials (High Reactivity Attapulgite) and the conventional mineral-filler materials (Portland cement), had achieved the Iraqi specification requirements.
2. The replacement of conventional mineral-filler materials (Portland cement) by the unconventional mineral-filler materials (High Reactivity Attapulgite) led to improve the Marshall-stability, Marshall-stiffness and reduce the fluidity (Marshall-flow).

3. The unconventional mineral-filler materials (High Reactivity Attapulgite) that used in production the asphalt mixtures was a lightweight and finer material which led to raising the viscosity of asphalt binder all this can increase in the stiffness of the mixtures and reduce the ITS in dry and wet specimens.

4. In this study, it can be remarked that the unconventional mineral-filler materials (High Reactivity Attapulgite) appeared a lower value to resist the water damage than the conventional mineral-filler materials (Portland cement) except the mixture MF2 is the opposite.

5. In the design of asphalt mixtures, can be recommended to use the high reactivity attapulgite (HRA) as a mineral-filler material in the asphalt pavement construction.

9. Acknowledgements

This research was supported by Al-Mustainsriya University (www.uomustansiriyah.edu.iq). Therefore, we would like to thank the Transportation laboratory at the Highway and Transportation Department, College of Engineering for their assistance to complete this study.

10. References

1. American Society for Testing and Materials (2018), "Road and Paving Materials: Vehicle Pavement System" (Annual Book of ASTM Standards, section 4, vol 04.03).

2. D. Lekhaz, Mallikarjun and Mandan (2016), "The Study of Bituminous Concrete Mix by Using Different Type of Fillers like Cement GGBS and Brick Dust" (Department of Civil Engineering Gurunanak Institute of Technology, Hyderabad, Telangana, India, vol 6 issue no. 8).

3. ASTM D1559 (2015), "Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus" Annual Book of ASTM Standards (West Conshohocken USA: ASTM International vol 4.03).

4. Al-Amide and Malik (2012), "Some Properties of Concrete Fired Local Attapulgite Clay" (MSc Thesis, University of Technology, Iraq).

5. Iraqi General Specification for Roads and Bridges (2003) "Standard Specification for Roads and Bridges Revised Edition" (Baghdad Iraq: The state Corporation for Road and Bridges, SORB).

6. Shobbar AL-Obaidey (2015), "Fresh and some Harden Properties of Lightweight Self Consolidation concrete Containing Attapulgite" (MSc Thesis, University of Technology).

7. American Society for Testing and Materials (2015) "Annual Book of ASTM Standards" (West Conshohocken USA: ASTM International, vol 4.03).

8. ASTM C618 (2015), "Standard Specification for Coal Fly Ash, Raw and Calcined Natural Pozzalona Material for Use in Pavement" Annual Book of ASTM Standards (West Conshohocken USA: ASTM International, vol 4.03).

9. Al-Qadi I, Elseifi M and Carpenter S (2007), "Reclaimed Asphalt Pavement a Literature Review" (Illinois Centre for Transportation, University of Illinois, series no.07-001).

10. ASTM D6931 (2015), "Standard Test Method for Indirect Tensile (IDT) Strength of Asphalt Mixtures" Annual Book of ASTM Standards (West Conshohocken USA: ASTM International, vol 4.03).

11. ASTM D4132 (2015), "Indirect Tensile Strength Ratio for Asphalt Pavement" Annual Book of ASTM Standards (West Conshohocken USA: ASTM International vol 4.03).

12. D. Whiteoak (1991), "The Shell Bitumen Handbook" (Thomas Telford, London, UK).

13. V. Sharma, S. Chandra and R. Choudhary (2010), "Characterization of Fly Ash Bituminous Concrete Mixes" (Journal of Materials in Civil Engineering, vol. 22, no. 12).