Marshall Parameters of Hot Mix Asphalt with Variable Filler Types and Aggregate Gradations

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Abstract. This research aims to evaluate the effect of aggregate nominal maximum size and type of filler on Marshall properties of asphalt mixture. A planned laboratory study is implemented by preparing the asphalt samples using locally available materials and an asphalt binder of 40-50 penetration grade (AC-20). Three types of aggregate nominal maximum size according to SCRB specifications and three types of fillers including limestone dust, cement and hydrated lime were used. Three bitumen contents were used led to nine types of mixtures were prepared and tested. The optimum asphalt content of the asphalt mixture was determined to be 4.75%w using the Marshall method of mix design. A total of 81 Marshall specimens were prepared and tested. The results showed that the aggregate nominal maximum size and filler type have a variable effect on Marshall properties while optimum asphalt content has a significant effect on Marshall Properties regardless of other variables in the mixture. Experimental results showed that using cement as a filler material can significantly increase the Marshall Stability compared to that of using hydrated lime and limestone dust.

1. Introduction

Asphalt concrete pavements are complicated functional structures that respond in a complex way to the effect of many factors (i.e., loads, materials, environmental conditions, mix types, mixture properties, etc.) and their interactions [1-4]. Generally, the durability of road pavement is a measure of the materials’ performance and ability to spread the applied traffic loading over an area longer periods without being affected by surrounding conditions [5]. Higher durability and stiffness of pavement layers results in wider resisting areas that reduce the level of strain experienced at the bottom of the pavement structure to a certain limit, while the cracking frequency increases with the increase in stiffness of the asphalt mix [6-10]. A completely stiff pavement structure is susceptible to cracking and deterioration.
since the road pavement must be able to deform as a result of thermal stresses and sublayers’ settlements [11, 12]. Stiffness test standards are used differently all over the world [13]. In the design of flexible pavement structures, the AASHTO design guide [14] and Marshall method are devised to design hot mix asphalt (HMA) mixtures. The first experiment of the Marshall mix design method was developed by Bruce Marshall in 1939. The procedure of this method is to use a drop hammer for sample compaction in a confined compression mould. Marshall stability and flow are then tested [15]. The mixture volumetric properties are also determined. Asphalt mixtures can be designed and optimised based on their composition and volumetric properties obtained from experimental methods [16]. Skilled technicians and experienced laboratory workers are required to identify properly the bitumen content and to evaluate the mixture’s performance. Some repeated laboratory tests are necessary for mixture optimisation. Any modification to the composition of the asphalt mixture in terms of type or quantity of bitumen, aggregate maximum size and filler types, would require new laboratory tests and investigations [17-19]. Fillers as one of asphalt mixture components have a crucial influence on the performance of asphalt mixtures by affecting the interlock between aggregate and bitumen [20-23]. There is a double benefit of adding fillers to asphalt mixtures, they can form a mortar or mastic asphalt when they blend with bitumen, as well as contribute in the homogeneity of the mixture as filler particles can perform as an additional aggregate then enhance the contact points between aggregate particles [24, 25]. In this way, fillers can improve the stiffness and durability of the mixture [26]. Generally, filler materials can perform several functions in the asphalt mixtures, as they can fill the voids, which decreases the optimum bitumen content. Also, fillers can increase the stability of the asphalt mixture, and enhance the bond between bitumen binder and aggregate [27]. The particle size distribution of the aggregate is called gradation and it is calculated as a percent of the total weight of asphalt mixture. Mampearachchi and Fernando [28] studied the influence of the aggregate gradation on the asphalt content of a mixture used for wearing course. Regression analysis has been implemented on results data to determine the relationship between aggregate gradation and asphalt content. The study has excluded the percentage of aggregate passing No. 4 (4.75mm) and No. 8 (2.36mm) from being influential on the asphalt content used for wearing course. However, the finer aggregate size usually requires relatively higher binder content to cover the solid particles, which shows, somehow, an existing relationship between aggregate gradation and bitumen content. In this way, gradation could be considered as the most crucial standard that can significantly affect the properties of asphalt mixtures, such as flow, stability, stiffness, permeability, resistance to moisture damage, skid resistance and fatigue resistance [29]. Lodhi et al. [30] investigated the influence of various aggregate gradations on asphalt mixtures, represented by Marshall properties. The study showed that the open-graded asphalt mixtures can exhibit higher stability values and lower flow values in comparison with dense-graded asphalt mixtures. Therefore, this research aims to focus on the effect of aggregate gradation more in detail and investigates the effect of type of filler and aggregate maximum size on Marshall Properties of asphalt mixtures.

2. Materials and methods

2.1. Asphalt materials
The used asphalt cement was of (40-50) penetration grade taken from Al- Dourah refinery. The physical properties and tests of the used asphalt cement are shown in Table 1.
Table 1. The Physical Properties and Tests of the Used Asphalt Cement.

| Property                                      | ASTM Designation | Test Result | SCRB Specification |
|-----------------------------------------------|------------------|-------------|--------------------|
| Penetration (25°C, 100gm, 5sec), (0.1mm)     | D–5              | 43          | (40 – 50)          |
| Kinematic Viscosity at 135°C, (cst).         | D–2170           | 405         |                    |
| Ductility (25°C, 5cm/min). (cm)              | D–113            | >100        | > 100              |
| Flash Point (Cleveland open cup), (°C)       | D–92             | 275         | min. 232           |
| Specific Gravity at 25°C                     | D–70             | 1.055       |                    |
| Penetration of Residue after thin from oven test (25°C, 100gm, 5sec) | D–5              | 33          |                    |
| Ductility of Residue, cm, (25°C, 5cm/min)    | D–113            | > 20        |                    |

The source of the aggregate used in this work is the quarry of Al-Niba’ee. This aggregate is widely used in Iraq for asphalt pavement. It was prepared by sieving and remixing in suitable proportions to meet the requirements of the state corporation of roads and bridges (SCRB) [13]. Three gradations were selected of aggregate with a nominal maximum size of (12.5 mm, 19 mm and 25 mm) with different percentages of filler. The physical properties supplied by the SCRB specification limits are presented in Table 2, which are met with the test results of the aggregate used in this research.

Table 2. Physical Properties of the Used Aggregate.

| Property               | ASTM Designation | Course Aggregate | Fine Aggregate |
|------------------------|------------------|------------------|----------------|
| Bulk                   | C-127            | 2.63             | 2.63           |
| Specific Gravity       | C-128            | 2.63             |                |
| Apparent Specific      | C-127            | 2.63             |                |
| Gravity                | C-128 & C-127    | 2.68             |                |
| % Water Absorption     | C-127 & C-128    | 2.8              | 0.5            |

Three types of mineral filler have been used which are limestone dust, hydrated lime, and ordinary Portland cement. Those types of fillers were brought from the lime factory in Karbala governorate. The physical properties of these three types are presented in Table 3.

Table 3. Physical Properties of the Used Types of Filler.

| Property               | Limestone Dust | Cement | Hydrated Lime |
|------------------------|----------------|--------|---------------|
| Specific Gravity       | 2.67           | 3.1    | 2.76          |
| Passing Sieve No.200   | %94            | %95    | %97           |
| (0.075 mm)             |                |        |               |

2.2. Specimen preparation
Specimens of Marshall size are to be used for the indirect tensile tests with the dimension of 63.5mm in height and 101.6mm in diameter and total weight around 1200gm including the combination of
aggregate with mineral filler and the asphalt cement. The three types of filler were used separately, and each type was added as 7% of the bitumen content.

2.3. Marshall test
This test was carried out according to the ASTM (D1559), which performed on cylindrical specimens of bituminous paving mixture loaded on the lateral surface and tested for the resistance to plastic flow by means of Marshall apparatus. The percent volume of aggregate, percent volume of binder, percent air voids, stability, flow were found for each prepared specimen, using ASTM methods and specifications. The Marshall stiffness was also determined for these specimens having different variables.

2.4. Stability and flow of Marshall specimens
The preparation of Marshall specimens and their testing were according to the procedure described in ASTM D1559. The asphalt specimens prepared were cylindrical with 2.5 in. height × 4.0 in. diameter. Before testing, these specimens were conditioned in a water bath at 60 °C for 30 minutes. Testing includes measuring the resistance to plastic flow after applying a load of constant rate (50.8 mm/min) until its highest value is reached. The resistance to the maximum load applied is called Marshall stability and the strain value corresponding to that maximum load were recorded as Marshall flow. The average value of three tested specimens for each type of asphalt mixtures was reported. Figure 1 shows the Marshall apparatus used in this research.

3. Results and discussion
Marshall Test was implemented to all specimens with their different variables to determine stability and flow. Marshall Stiffness was also determined which is the ratio between stability and the corresponding flow for all different specimens. These results are represented in the following sections.
3.1. Effect of aggregate nominal maximum size on Marshall stability
Three types of aggregate were used in this research. The results obtained from experimental work showed that Marshall stability is affected by the size of the aggregate used. Figure 2 shows the change in Marshall stability with the variation of the nominal maximum size of aggregate and the effect of upper and lower limits of aggregate. It is observed that the Marshall stability is affected by the bitumen content and aggregate maximum size used. The lower bitumen content would result in lower Marshall stability despite the size of the aggregate used.

Figure 2. Effect of aggregate maximum size on Marshall stability.

The optimum bitumen content used in this research (4.75% w) has shown the highest stability of Marshall specimens with an aggregate nominal maximum size of 25 and 19 mm. While samples of the aggregate nominal maximum size of 12.5 mm have shown higher stability at bitumen content of (5% w). This can be attributed to the higher VMA created by coarser aggregate gradations, which produce a good mechanical bond between bitumen and aggregate particles. The lower strength of smaller size aggregates requires more binder content to increase the cohesion between particles and then the stability of the sample.

3.2. Effect of aggregate nominal maximum size on flow
In general, the values of Marshall flow give an indication of the mixture’s ability to resist permanent deformation that can happen due to traffic loads. Higher flow values can explain that the mixture is plastic, which makes it prone to plastic deformation or rutting. On the other hand, lower flow values make the asphalt mixture more brittle, which might result in different types of cracks throughout the pavement service life. Figure 3 shows the aggregate nominal maximum size effect on Marshall flow. The presented results show the significant decrease of the Marshall flow corresponding to the decrease of bitumen content regardless of the aggregate maximum size used. The flow increased with increasing bitumen content and it seems like a linear increase without any consideration of the aggregate maximum size used in the mixture. This trend could be attributed to the higher than normal voids and insufficient bitumen for durability in the asphalt mixture.
3.3. Effect of aggregate nominal maximum size on stiffness
The efficient resistance to traffic loading can be a result of high stiffness of the asphalt mixture. However, higher stiffness can be an indicator of lower flexibility, which directly affects the highway’s long-term performance. Besides, higher stiffness values could lead to thermal cracks to take place in asphalt pavement surface in future. Figure 4 presents the influence of aggregate maximum nominal size on Marshall stiffness. It can be seen that the stiffness increases with decreasing the bitumen content in the asphalt mixture regardless of the aggregate particle size. Which is expected as the stiffness is the function of Marshall stability and flow. The highest stiffness recorded in this research was with a maximum nominal size of 19mm and bitumen content of 4%. No significant difference in Marshall stiffness is noticed with other mixtures since its value was between 2.5 and 3.1 kN/mm.

3.4. Effect of type of filler on Marshall stability
The function of the mineral filler is usually to fill the voids in the aggregate framework and to improve the properties of the asphalt mixture. The lesser voids the higher stability of the material and the lower deformation. The effect of filler type is depending upon the fineness of filler and its specific gravity. Figure 5 presents how these types of fillers affect Marshall stability.

![Figure 5](image)

**Figure 5.** Effect of mineral filler on Marshall stability.

It can be observed that the optimum bitumen content provided higher stability in all three types of fillers. Also, the cement filler has shown higher stability than the limestone dust and the hydrated lime. This can be attributed to the cementitious property of cement filler, which adds strength to the material as well as a binding agent.

3.5. **Effect of filler type on Marshall flow**

Figure 6 shows that the Marshall flow was increased significantly with the increase of bitumen content regardless of the type of filler used. The increase seems to be linear with the percentage of bitumen content with all types of fillers. The effect of filler on Marshall flow seems to be insignificant as it shows the same trend with almost the same value of flow to all types of fillers. The reason for that could be due to the dominant bitumen effect on Marshall flow.

![Figure 6](image)

**Figure 6.** Effect of mineral filler on Marshall flow.
3.6. Effect of filler type on stiffness
The filler is one of the main components of asphalt mixture that consist of mineral particles passing through the 0.075 mm sieve. Filler materials used in this research are limestone dust, hydrated lime and cement, as mentioned in the previous sections. The necessity of fillers in asphalt mixtures is that they can perform as a binder extender that can perform two purposes. First, the filler material can fill the voids in the asphalt mixture, and this can enhance the density and durability of the asphalt mixture. Second, fillers can increase the stiffness of the asphalt mixture and hence improve the resistance to rutting. Therefore, the type of filler material and bitumen content can significantly affect Marshall stiffness. It can be observed from Figure 7 that Marshall stiffness is higher when using cement as a filler, while hydrated lime and limestone dust exhibit almost similar stiffness values.

Fillers can also improve the stiffness of the bitumen that eventually increases Marshall stability. In this way, using cement as a filler in the asphalt mixture can enhance the stiffness of the bitumen and hence the total asphalt mixture. It can be noticed that with the same bitumen content, the stiffness is higher in cement filler. However, the percent filler used should be within specifications of the AASHTO design guide of asphalt mixture and ASTM D1559. Increasing the filler would act as a bitumen extender, which can lead to increasing the flow of the mixture and adversely affecting its durability.

4. Conclusions
According to the results presented in this research, the following conclusions can be drawn:
- Bitumen content can control the asphalt mixture properties such as Marshall stability and flow regardless of the aggregate nominal maximum size used and type of filler.
- Optimum asphalt content showed the highest stability and stiffness with all types of fillers.
- Marshall stability was increased considerably when using an aggregate maximum nominal size of 19 mm, which shows a relevance with the optimum mixture requirements. Larger aggregate size would cause higher voids and less mechanical bonds between aggregate and bitumen, which can lead to a weaker asphalt mixture.
- Marshall flow was affected significantly by the bitumen content in the asphalt mixture regardless of the aggregate nominal maximum size and type of filler.

Because of practical considerations, many constraints were imposed upon this study in terms of variables included in the experimental design. Accordingly, in future research, it is recommended to use other
material variables such as the effect of bitumen type including its chemical composition and rheological properties, and the use of available additives to improve the asphalt mixture.

5. References

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