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The Effect of Filler Type on the Hot Mix Asphalt Behavior

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Abstract

The test have been done on many samples of Hot Mix Asphalt using many types fillers like Portland Cement, Limestone, Hydrated Lime as a filler, 1% Hydrated Lime added to conventional mixture, Portland Cement introduced in cold state, and passing sieve no.200 dust (conventional mixture).

In this research, Marshall test procedure is used to investigate the potential prospects to enhance Hot Mix Asphalt properties. The objectives also include determining which one of the additives is better than the others to be used and the method of introducing this filler type to the mixture.

According to the results, we found out that the better filler affects the mechanical properties of Hot Mix Asphalt is Portland cement when it introduced with the aggregate at the mix temperature.

تأثير نوع المادة المالئة على تصرف الخلطة الاسفلتية الساخنة

الخلاصة

لقد تم إجراء الفحص على نماذج للخلطة الإسفلتية الساخنة تضم عدة أنواع من المواد المالئة هي (الإسمنت البورتلندي الاعتيادي, الغبرة, النورة المطفئة, الغبار العابر من منخل رقم (200), ثم تم استخدام الإسمنت بحالته الاعتيادية (دون تسخين), و أخيرا استخدام النورة المطفئة كمضاف بنسبة 1% إلى الخلطة المرجعية التي تم استخدام العابر من منخل 200 كمادة مالئة لها.

في هذا البحث, استخدمت طريقة فحص مارشال للتعرف على إمكانية تحسين الخواص الميكانيكية للخلطة الإسفلتية الساخنة. كذلك يهدف البحث إلى تحديد الأفضل من بين هذه الأنواع من المواد المالئة للاستخدام و كذلك الطريقة الامثل لإدخال هذه المواد إلى الخلطة الإسفلتية.

لقد وجد من نتائج التحليل أن أفضل مادة مالئة من حيث التأثير على الخواص الميكانيكية هو الإسمنت البورتلندي عندما يدخل مع الركام بدرجة حرارة الخلط.

1-Introduction

It has long been recognized that the filler plays a major role in behavior of the asphalt mixtures. Fillers fill voids between coarse aggregates in the mixture and alter properties of the binder, because the filler acts as an integral part of the mastic (combination of bitumen, filler, and entrapped air). The quality of mastic influences the overall mechanical performance of asphalt mixtures, (Kim and others, 2003).

In this study, Marshall mixes will be designed for surface course. One of the advantages of the Marshall Mix Design method is that the performance of the mixes can be expected for local materials and environmental impact. The experimental work in this study provides a comparison among six types of mixtures using four filler types. We used Portland cement, Passing sieve No.200 dust, hydrated lime, and Limestone as fillers, in addition to the use of hydrated lime as an additive by introducing 1% of it in the mixture of passing No.200 filler, and the sixth mixture type is by using Portland cement in cold state by

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introducing it at the mix moment without heating to the mixing temperature.

The work was limited to one type of gradation and one source of aggregate and asphalt cement. One nominal maximum size aggregate (12.5mm) was used in these mixes.

1-1 Objective of the Study

The primary objectives of this study are to investigate the effect of filler type on the fundamental behavior of asphalt concretes and to examine ways in which the filler introduction procedure can further influence these behaviors using one volumetric mix design, and to compare the fundamental behaviors of various mixtures to determine which type of the fillers is better than the others when used locally.

2- Literature Review

2-1 Introduction

During the last two decades, the amount of vehicle miles traveled per year and the amount of equivalent single axle loads, ESAL, have increased by 75 and 60 percent respectively. As a result, hot mix asphalt HMA, pavements have struggled to perform the intended design life, presenting rutting, fatigue and thermal cracking problems. This has created a need to develop an enhanced hot mix asphalt concrete design procedure (2).

For approximately the past 50 years, engineers have designed asphalt mixtures using the Marshall or Hveem mix design methods, and over this period, different highway agencies have modified these design procedures to better fit their particular needs. Both methods have proven to be satisfactorily effective in aiding the design of highways and interstates, but some problems exist.

The primary problem is that both the Marshal and Hveem design methods are empirical- they do not produce samples that share the properties or performance of the finished product. This makes it difficult to accurately predict how a particular mix will perform in the field (14).

Hot mix asphalt (HMA) is the most common material used for paving applications in the world. It primarily consists of asphalt cement binder and mineral aggregates. The binder acts as an adhesive agent that binds aggregate particles into a cohesive mass. When bound by asphalt cement binder, mineral aggregate acts as a stone framework that provides strength and toughness to the system. The behavior of HMA depends on the properties of the individual components and how they react with each other in the system.

2-2 Marshall Mix Design Method

Bruce Marshall, formerly the bituminous engineer with the Mississippi state highway department, developed the original concept of the Marshall method of designing asphalt pavements. The present form of Marshall mix design method originated from an investigation started by the US army corps of engineers in 1943 to develop a simple apparatus for airfield pavements with increased wheel loads during World War II. These engineers also evaluated various compaction efforts, such as impact compaction, and produced densities in the laboratory that were similar to those achieved in the field. In addition, they simulated aircraft loadings in order to select the proper, optimal asphalt content. The number of blows and the foot design for the compactor were determined as a standard. Initial criteria were established and upgraded for increased tire pressures and loads. The purpose of Marshal method is to determine the optimum asphalt content for a particular blend of aggregates and traffic level. The optimum asphalt content is determined by the ability of a mix to satisfy stability, flow, and volumetric properties, (17).

2-3 Material Selection

2-3-1 Asphalt Cement

Before a good asphalt mix can be designed by Marshall method, designers must select the proper asphalt cement grade and determine its properties. They decide on a proper asphalt cement grade by examining the type of asphalt mix being designed and the geographical location of its use. After the asphalt cement is selected, designers may determine its viscosity and whether the asphalt meets specifications of flash point, penetration, ductility, and solubility. Once they conclude that asphalt cement is acceptable. They find its specific gravity and create a temperature – viscosity plot to determine its appropriate mixing and compaction temperatures (9).

2-3-2 Aggregate

For the requirement of successful mix, the appropriate aggregate also must be selected when decision accepted particular aggregate, they test its gradation specific gravity, and absorption. Then, they determine the aggregate gradation to be used in a mix.

Aggregates are the second principal material in HMA. They play an important role in the performance of asphalt mixtures. For HMA, they make up about 90 to 95 percent by weight and comprise 75 to 85 percent of the volume (9 & 4). Therefore, knowledge of aggregate properties is crucial to designing high quality HMA mixtures.

The shear strength is mainly dependent on the internal friction provided by the aggregate. Here, the shape and texture of the aggregate play important role in providing the required interlock. Cubical, rough-textured aggregate provide more shear resistance than rounded, smooth-textured aggregate. The internal friction provides the ability of aggregate to interlock and create a strong mass that is able to resist the applied traffic load.

2-3-3 Filler

Asphalt mixture have an optimum co hesion where maximum compaction will occur. This cohesion can be effected by the amount of filler used in a mix. Santucci and Shcmidt, 1962 (18), showed that if the binder volume (asphalt + filler) is held constant, there is an optimum filler percentage where maximum compaction can occur. A study by Heukelom, 1965 (11) also showed that the amount of filler used in a mix could influence how well a mix is compacted. For a given filler type, the ease of compaction increases with the percentage of filler in the overall binder content.

It has long been recognized that the filler plays a major role in behavior of the asphalt mixtures. The importance of fillers in asphalt mixtures has been studied extensively by Anderson and Goetz (1973) (3). Fillers fill voids between coarse aggregates in the mixture and alter properties of the binder, because the filler acts as an integral part of the mastic (combination of bitumen, filler, and entrapped air). The quality of mastic influences the overall mechanical performance of asphalt mixtures as well as placement workability.

An interactive physico-chemical effect between the filler and the bitumen related to the fineness and surface characteristics of the filler typically influences fatigue fracture characteristics. According to a study by Craus et al. (1978) (7), the physico-chemical aspect is related to adsorption intensity at the filler-bitumen interface, and higher surface activity significantly contributes to stronger bonds at the filler-bitumen interface. It can be inferred that the interactive role associated with the physico-chemical reaction is influenced by the type of bitumen and filler as well. Lesueur and Little (1999) (16) demonstrated that hydrated lime reacts quite differently as a filler with asphalt. They hypothesized that hydrated lime interacts with some of the plentiful polar components of asphalt. The different interactions between hydrated lime and asphalt have subsequently been documented by Hopman et al. (1999) (12).

Mineral fillers have traditionally been used in asphalt mixtures to fill the voids between the larger aggregate particles. Generally, the aggregate material passing the No.200 sieve is referred to as filler. In ASTM D242, mineral filler is defined as consisting of finely divided mineral matter, such as rock dust, slag dust, hydrated lime, hydraulic binder, fly ash, loess, or other suitable mineral matter. Other materials, such as carbon black and sulfur, have been used primarily to modify asphalt binder properties, but they do have a role as filler, also (1).

Typically, an increase in filler lowers the optimal asphalt content, increases the density, and increases the stability.

All fillers must be fed to the asphalt mixture consistently and in correct proportions; otherwise, the mix properties are adversely affected. Excessive amounts of filler usually reduce the voids in mineral aggregate (VMA) to a point where sufficient asphalt content for a durable mix cannot be added. High filler content also increases the aggregate surface area and, thus, greatly reduces the asphalt film thickness. Further, mineral filler characteristics vary with the gradation of the filler. If the size of the mineral filler particles is smaller than about 10 microns, the filler acts as an extender of the asphalt cement because the thickness of most asphalt films in dense-graded HMA is less than 10 microns. If the mineral filler size is larger than 10 microns, it acts more like an aggregate. If an excessive amount of this larger sized mineral filler is present, the asphalt content may increase because of increased VMA. Therefore, care must be taken to consider not only the amount of mineral filler, but also its size when evaluating whether an excessive amount of fine material is present in a mix that is being designed or controlled in the field (9).

2-3-4 Additives

One additive type, Lime, have been used in this study. It is important to other researches, which have utilized hydrated lime.

Hydrated lime has long been recognized as a highly beneficial component of hot mix asphalt, based initially on its ability to reduce stripping. More research and experience have demonstrated that limes benefits are much broader, and include:

- increased mix stiffness and reduced rutting.
- Reduced oxidation and age-hardening effects.
- Improved low-temperature cracking resistance.

It has been proved through laboratory and field testing that hydrated lime in HMA substantially reduces moisture sensitivity. Lime enhances the bitumen-aggregate bond and improves the resistance of bitumen itself to water-induced damage. Recent surveys document the success and acceptance of lime in HMA (8).

3- Methods of Introducing Hydrated Lime into Mixes

Even though it has been shown repeatedly that the use of hydrated lime in asphalt concrete mixtures is beneficial, confusion still exists as to the best method for adding lime to asphalt mixtures. In general, contractors and/or transportation departments have adopted one or more of three popular techniques that incorporate lime into HMA. The three techniques, along with a brief description of each and the major positive and negative features of each, are listed in Table (1) (6).

3-1 Addition of Dry Hydrated Lime to Dry Aggregate

Adding dry hydrated lime to dry aggregates is the simplest method of introducing hydrated lime to asphalt mixes. This method was first adopted by the state of Georgia in the early 1980s. In this method, hydrated lime and mineral filler are added in a drum mixer immediately after the asphalt is introduced. Hydrated lime thus comes in contact with the aggregates directly, resulting in an improved bond between the aggregate and asphalt. The portion of lime that fails to come in contact with the aggregate gets mixed in with the asphalt. This reaction of the lime with highly polar molecules in the asphalt forms insoluble salts that no longer attract water, thus reducing the stripping and oxidation potential.

3-2 Addition of Dry Hydrated Lime to Wet Aggregate

Adding dry hydrated lime to wet aggregate is the most general method of adding hydrated lime to asphalt mixes. In this method, hydrated lime is metered into aggregate that already has a moisture content of 2% to 3% over its saturated-surface-dry (SSD) condition.

After hydrated lime is added to the wet aggregate, the lime-aggregate mix is processed in a pugmill to insure thorough mixing. The advantages of introducing dry hydrated lime to wet aggregate are that the asphalt mixture provides better coverage and allows for proper application as compared to the method that adds dry hydrated lime to dry aggregate. These advantages are possible because moisture ionizes lime and helps distribute it on the surface of the aggregate. The portion of hydrated lime that does not adhere to the aggregate eventually gets mixed with the asphalt, thus contributing to the same improvements that are inherent of the dry method. The main disadvantage of this method is the extra effort and fuel required to dry the aggregates before mix production. When using this method of adding hydrated lime, many states require that the lime-aggregate mix marinate for about 48 hours.

3-3 Addition of Hydrated Lime in the Form of Slurry

In this method of adding lime, a slurry mixture of lime and water is metered and applied to the aggregate to achieve a superior coverage of the stone surfaces. Lime slurries are made from hydrated lime, but sometimes quicklime is also used. The treated aggregates can be marinated or used directly. The advantages of using this method include:

1) The resistance of HMA to stripping;
2) Minimal lime dispersion due to dusting and blowing; and
3) The fact that it provides the best coverage of lime over the aggregate.

The disadvantages of using lime slurries include:

1) Fuel consumption during the drying process; and
2) The need to purchase and maintain specialized costly equipment.

4- Experimental Work

4-1 Introduction

Marshall mix design was used, first to determine the optimum bitumen binder content and then further to test the mixtures properties of the various filler types asphalt mixtures. In total, 90 samples were prepared to investigate the optimum asphalt content of the various mixes and to specify properties of them. Five proportions of asphalt cement binder were used for each mix type and state by weight of the total mix (4, 4.5, 5, 5.5, and 6). The tests include the determination of bulk specific gravity, maximum (theoretical) specific gravity, stability and flow. Marshall mix design requires the determination of the percentages of air voids, air voids of mineral aggregate, and voids filled with asphalt.

One binder (40/50) was used in this study had been produced by al-dorah refinery. Four filler types were used (No. 200 passing dust, Portland cement, hydrated lime, and limestone), in addition to the use of the hydrated lime as an additive. The properties of the binder are listed in Table (2).

One aggregate source was used for preparing samples. Hydrated lime, which was used as an anti-strip additive, and it was added at a rate of 1% by dry mass of aggregate.

4-2 Materials

The materials used in this study are locally available and selected from the currently local materials used in roads construction in Iraq.

4-2-1 Bituminous Material

Asphalt binder 40/50 penetration grade from Al-Dorah refinery was used in this research. The laboratory tests performed to evaluate the bitumen properties were: Specific Gravity, Ductility, Flash Point and Penetration, and Softening point. The properties of asphalt binder, which are presented in Table (2), are within the specification of penetrated asphalt grade (40/50).

4-2-2 Coarse Aggregate

The coarse aggregate (crushed) is brought from the hot asphalt plant of Al-Nibaee quarry at Al-Taji. The size of coarse aggregate range between 1/2 in. (12.5mm) and No.4 sieve (4.75mm). The physical properties of the coarse aggregate are shown in Table (3).

4-2-3 Fine Aggregate

The fine aggregate is brought from the hot asphalt plant of Al-Nibaee quarry at Al-Taji. The gradation of fine aggregate is passing No.4 (4.75mm) sieve and retained on sieve

No.200 (0.075mm). The physical properties of the fine aggregate are shown in Table (3).

4-2-4 Fillers

The filler, as defined in this study, is the material passing the 0.075 mm sieve. Four different filler types were selected for this study to be having six mixtures depending on filler type and the method of entrance of filler. Portland cement, hydrated lime, passing sieve No. 200 dust, and limestone dust were tested as fillers, and addition of 1% of hydrated lime to passing sieve No.200 dust mixture, and entering of Portland cement without heating to the mix temperature in this study. Table (4) shows the specific gravity for the filler types used in this study.

4-3 Combination of Aggregate Gradation

The coarse and fine aggregates was washed, dried, sieved and separated to various sizes. In this study, one nominal maximum size was selected (12.5 mm) with one aggregate gradation, Table (5). The aggregate fractions were then recombined in the proper proportions to meet the chosen gradation.

4-4 Preparation of Asphalt Concrete Specimens

The first step in the mix design is the determination of relative proportion of the asphalt and aggregate as well as percent of each aggregate size fractions involving filler, and the efficiency of mixing procedure which depends on providing homogeneous mix and uniform coating of aggregate with asphalt.

The mixing procedure may be divided into two stages, as described in the following articles:

4-4-1 Preparation of Aggregate

The aggregate and filler for asphalt mixes are prepared using the following procedure:

The aggregates are first dried to a constant weight at (110 C°), separated to the desired sizes by sieving and recombined with the mineral filler to conform the selected gradation requirements of that specification for surface course revealed in table (5) (13).

The total weight of the batch is approximately 1200 gm to produce a specimen of 2.5in. (63.5mm) height by 4in. (101.6mm) diameter. All aggregate sizes and filler are placed in the mixing bowl. The aggregate and filler are then heated before mixing with asphalt cement to a temperature of (160 C°).

The process of adding dry hydrated lime to dry aggregates is the simplest method of introducing hydrated lime to asphalt mixes. In this method, hydrated lime and mineral filler are added in a mixer immediately after the asphalt is introduced. Hydrated lime thus comes in contact with the aggregates directly, resulting in an improved bond between the aggregate and asphalt. The portion of lime that fails to come in contact with the aggregate gets mixed in with the asphalt. This reaction of the lime with highly polar molecules in the asphalt forms insoluble salts that no longer attract water, thus reducing the stripping and oxidation potential.

The process of adding the dry hydrated lime to wet aggregate is as follow: in this method, hydrated lime is metered into aggregate that already has a moisture content of 2% to 3% over its saturated-surface-dry (SSD) condition. After hydrated lime is added to the wet aggregate, the lime-aggregate mix is processed in a pugmill to insure thorough mixing. The portion of hydrated lime that does not adhere to the aggregate eventually gets mixed with the asphalt, thus contributing to the same improvements that are inherent of the dry method. After that the lime-aggregate mix marinate for about 48 hours.

4-4-2 Preparation of Binder

The asphalt cement for conventional mixture is heated on a hot plate to the temperature of (140 C°) before mixing with aggregate.

4-4-3 The Process of Mixing

Five percentages (4, 4.5, 5, 5.5, and 6%) of asphalt cement are used for each mixture type. The binder weighted to the desired amount and then added to the heated aggregates and filler in the mixing bowl. All components are mixed thoroughly until all the aggregate and filler particles are completely coated with asphalt. The mixing temperature is maintained within the required limit (155-165 C°) for the mixture.

4-5 Resistance to Plastic Flow of Asphalt Mixture (Marshall Test Method)

This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to ASTM (D1559) (1). This method includes preparation of cylindrical specimen which are 4 inch (101.6mm) in diameter and 2.5inch (63.5mm) in height.

The Marshal mold spatula, and compaction hummer are heated on a hot plate to a temperature between (120-150C°). The asphalt mixture is placed in the preheated mold and it is then spaded vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior.

The temperature of the mixture immediately prior to compaction is between (142-146 C°). Then, 75 blows in the top and bottom of the specimen are applied with a compaction hummer of (4.535 Kg) sliding weight, and free fall in 18inch. (457.2mm). the specimen in mold is left to cool at room temperature for 24 hours and then removed from the mold.

Marshal stability and flow test are performed on each specimen. The cylindrical specimen is placed in a water bath at 60C° for 30 t0 40 minutes and then compressed on the lateral surface at constant rate of 2in/min. (50.8mm/min.) until the maximum load (failure) is reached.

The load resistance and the corresponding flow value are recorded. Three specimens for each combination are prepared and the average results are reported.

The bulk specific gravity and density ASTM (D2726), theoretical (maximum) specific gravity of voidless mixture are determined in accordance with ASTM (D2041). The percentage of air voids is then calculated (1).

5- Results and Analysis

5-1 Analysis of Results from Marshall Test

The acceptance tests on the aggregates and asphalt cement of HMA should pass the procedure included in the ASTM D1559 "Resistance to plastic flow of bituminous mixtures using the Marshall apparatus". The Marshall criteria includes minimum amount of voids in mineral aggregates (VMA), a range of acceptable air void contents, a maximum stability and a range of flow values, and in sometimes the percent of voids filled with asphalt (VFA) should be within a specified range.

The first step in the analysis of the results is the determination of the average bulk specific gravity for all test specimens having the same asphalt content, the same filler type, and the same mixing method. The average unit weight of each mixture is then obtained by multiplying its average specific gravity by the density of water (γw). A smooth curve that represent the best fit of plots of unit weight versus percentage of asphalt is determined, as shown in figure (1). This curve is used to obtain the bulk unit weight values that are used in further computations.

Five additional separate smooth curves are drawn: Marshall stability versus percent of asphalt, Flow versus percent of asphalt, percent voids in total mix versus percent of asphalt, percent voids in mineral aggregate versus percent asphalt, and percent voids filled with asphalt as shown in figures (2) to (6). These graphs are used to select the asphalt contents for maximum stability, maximum unit weight, and percent voids in total mix within the limits specified (usually the median of the limits) (3-5%). The average of the asphalt contents is the optimum asphalt content. The stability and flow for the optimum content can then be obtained from the appropriate graphs to determine whether the required criteria are met. Suggested criteria for these test limits are given in Table(6) according to Iraqi specification revised in 2003.

The effect of these types of filler on Marshall test properties are shown in the following figures, where:

HL ----------Hydrated Lime
PC ----------Portland cement
CPC --------Cold Portland cement
LS ----------Limestone
1% HL ------Hydrated Lime as an additive by adding 1% of it to the conventional mix
Passing #200 -------- Conventional or control group which contain the passing dust from sieve No. 200 as a filler.

5-2 The Comparison among the Various Types of Asphalt Mix Types

The best mix is selected as the filler type mixture that satisfies the following:

* Maximum bulk density.
* Maximum Marshall stability.
* Minimum flow or the closest to 3mm.
* The minimum Air Voids or the closest to 4%.
* Maximum V.M.A. content.
* The most satisfactory V.F.A..

The maximum bulk density was reported for asphalt mixture with limestone dust filler at proportion of asphalt content (5.5%) by total mix Figure (7). In general, mixture with limestone, Portland cement, and passing No, 200 sieve dust modified with 1% of hydrated lime have a higher bulk density than those with passing No, 200 filler dust and hydrated lime filler. We can notice a significant difference between mixture of hydrated lime filler and the other mixes of different filler types, due to the high percent of air voids that caused by lime existing and its swelling up by the effect of mixing heating.

The maximum stability (13.55 KN) was reported for asphalt mixture with hydrated lime at bitumen proportion 0f 5.5% by total weight of mix. Figure (8) shows that mixture with hydrated lime cold Portland cement and passing No. 200 dust filler with 1% hydrated lime have a higher stability than those with lime stone and passing sieve No. 200 dust filler.

The value of flow of optimum asphalt content mixture (3.15 mm) was reported for asphalt mixture with passing No. 200 sieve dust with 1% hydrated lime and in the same time it's the nearest value to 3mm average of allowable flow that range from (2-4) mm.

It may be noticed, that most optimum asphalt contents flow are within the accepted range except that for limestone filler it was (5.15 mm). See Figure (9).

The minimum percentage air voids of asphalt mixture (1.9 %) at (5.06 %) optimum asphalt content to mix with cold PC, that mean out of specification range (3-5%) while the nearest value to 4% was 3.65% for the mixture with passing sieve No.200 dust filler.

Figure (10) shows that the OAC mixture of AV % value of mixtures with cold Portland cement and passing sieve No.200 dust with 1% hydrated lime are less the 3% , that mean small air voids content. While it is very high with mixture of hydrated lime filler.

The maximum percentage VMA of asphalt mixture 16.2 % was reported for asphalt mixture with hydrated lime filler at 5% OAC of that mixture while the minimum value was (12.05 %) for asphalt mix of lime stone filler (below the specification) other mixture types are within or below 14% the minimum limit. See Figure (11).

6-Conclusions and Recommendations

Conclusions and Recommendations drawn from the results discussed in this dissertation are presented in this article.

6-1 Conclusions

After the analysis had been done, the following situations may be met:

1- Low voids and low stability: This situation may be met with Limestone filler asphalt mixture. In this situation, the voids in the mineral aggregates can be increased when adding more coarse aggregates. Alternatively, the asphalt content can be reduced, but no need to do that in our case because the asphalt content is not higher than that normally used, then the fine aggregate and filler amount can be reduced (0.5 - 1 %) to solve this problem.

2- Low voids and satisfactory stability: This situation may be met with cold added Portland cement (CPC) and passing no.200 dust modified with 1% hydrated lime (1% + Pass no.200 dust). This mix can cause reorientation of particles and additional compaction of the pavement with time as continued traffic load is imposed on the pavement. This may lead to instability or flushing of the pavement. This mixes should be altered by adding more coarse aggregate.

3- High voids and satisfactory stability: This situation may be met with Hydrated Lime dust asphalt mix type.

High voids should be reduced to acceptable limits (AV 3-5%), even though the stability is satisfactory. This can be achieved by increasing the amount of mineral filler dust in the mix (0.5-1.2 %) by weight of total mix.

4- Satisfactory voids and low stability: This situation may be met with passing No.200 sieve dust filler asphalt mix type. This condition suggests low quality aggregates or almost low quality filler type, because this filler type contains high percent of clay, and this is not required in asphalt mix, then the quality should be improved.

5- Satisfactory voids and satisfactory stability: this case was happened with Portland cement hot mixed with the aggregates. It is the best filler type cause this mix had met all criteria successfully.

6- A part of the present experimental study has been made by adding 1% hydrated lime in the asphalt mixtures. The results have shown that it did have a better performance than the conventional type of fillers, but the evaluation of including different percentages of additives in the mixtures was not considered here.

6-2 Recommendations

1- The results of this study were obtained in the laboratory, which might require long term on-site tests to examine the difference and to further check the usefulness of each test. Above all, the present study has complied with the applicable codes, and previous research based on the topic of preventing road surface damages. The results might provide a useful reference when constructing a road with regional characteristics similar to Iraq.

2- The author is recommend to use the Portland Cement as a filler as it provides the best mechanical and volumetric properties among the other filler types.

6-3 Future researches

From the findings of this research, the following recommendations are made:

1- The properties and proportions of the materials in a hot-mix asphalt need to be measured carefully and consistently using standard ASTM or AASHTO procedures so that their effect on performance can be evaluated.

2- The influence of aggregate type. Chemical composition, asphalt grades, and asphalt composition on the asphalt concrete mix ability against moisture damage can be studied.

3- Comparison study to evaluate sensitivity of asphalt mixes against moisture damage by using AASHTO approach and superpave approach can be carried out.

4- The influence of compaction by using Marshall method on moisture sensitivity when adding antistripping agents to HMA mix can be studied.

5- The bulk specific gravity of the aggregate must be accurately determined in the design phase. It is apparent that the lack of precision in determining aggregate bulk specific gravity and absorption will directly cause poor precision in determining VMA. Standard ASTM and/or AASHTO procedures must be followed carefully.

6- The tendency for increased absorption due to higher temperatures and/or increased storage time should be determined for specific aggregate sources. This can be accomplished by running bulk specific gravity and maximum theoretical specific gravity tests on mixes using the same aggregate with various temperatures and storage times as a special study on some projects around the country.

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Table (1) Lime Addition Techniques

Method	Description	Major Positives	Major Negatives
Dry	– Simplest method – Lime and mineral filler introduced immediately after introduction of asphalt	– Least expensive method – Direct contact between aggregates and hydrated lime – Lime and mineral filler introduced immediately after introduction of asphalt	– Dusting and lime loss – Minimal mixing and coating of aggregates
Wet	– Lime metered into aggregate at a moisture content of 2-3% higher than SSD condition – Mixture processed in pugmill to ensure thorough mixing	– Proper coverage and application – Portion not mixing with aggregate will mix with asphalt, thus still aiding as anti-stripping agent	– Expensive due to extra fuel needed to dry aggregates before mix production
	– Aggregates kept in moist condition and marinated for up to 48 hours	– Moisture content slowly reduces over stockpiling period – Stockpiling can be separated from production, thus providing an economic advantage	– Aggregate handling effort is increased – Storage space needed for aggregate stockpiling – Concerns over carbonation of stockpiles with long stockpiling times
Slurry	– Slurry of lime and water applied to aggregates – Marinating optional	– Improved coverage of aggregates – Reduced dispersion and loss of lime – Improved stripping protection	– Increased water and fuel costs – Expensive, specialized equipment requirements

Table (2) Properties of Used Asphalt Binder

Test*	**Test results**	**Specification**	
		Minimum	Maximum
Specific gravity (g/cm3) –ASTM D-70	1.013	1.01	1.06
Ductility (cm) – ASTM D113-99	132	100	
Flash point (c°) – ASTM D22-78	(309)	250	
Penetration (0.1 mm) –ASTM D-97	(42-45)	40	50
Softening point (c°)	(51)	46	56

* **These tests had been made in asphalt technology laboratory of Al-Mostansiriyah University – College of Engineering.**

Table (3) Physical Properties of Nibaee Aggregates.*

Property*	Coarse aggregate	Fine aggregate
Bulk Specific gravity (g/cm3) (ASTM C127 and C128)	2.607	2.525
Apparent Specific gravity (g/cm3) (ASTM C127 and C128)	2.637	2.557
Percent water absorption (ASTM C127 and C128)	0.435	1.40
Percent wear (Los-Angeles Abrasion) (ASTM C131)	19.69	…..

*The test was done in corporation with National Center for Construction Laboratories and researches.**

Table (4) Specific Gravity of The Used Filler Types.*

Filler type	Specific gravity
Passing No.200 sieve dust (P No.200)	2.727
Portland cement (PC)	3.15
Hydrated Lime (HL)	2.50
Limestone (LS)	2.70

*The test was done in corporation with National Center for Construction Laboratories and researches.**

Table (5) Gradation of The Aggregate for Surface Course.

Sieve size		Specification % passing	Selected Gradation of Aggregate
Imperial	mm		
3/4 in.	19	100	100
1/2in.	12.5	90-100	95
3/8in.	9.5	76-90	83
No.4	4.75	44-74	59
No.8	2.36	28-58	43
No.50	0.25	5-21	13
No.200	0.075	4-10	7

Table (6) Suggested Criteria for Test Limits.*

Marshall Method Mix Criteria	Surface course Type ш A	
	Min.	Max.
Compaction, number of blows each face of specimen	75	
Stability, kN	8	
Flow, mm	2	4
Percent of Air Voids	3	5
Percent Voids in Mineral Aggregates	14	
Percent Voids Filled with Asphalt	70	85

* **These limits of Iraqi specifications of surface course type ш A.**

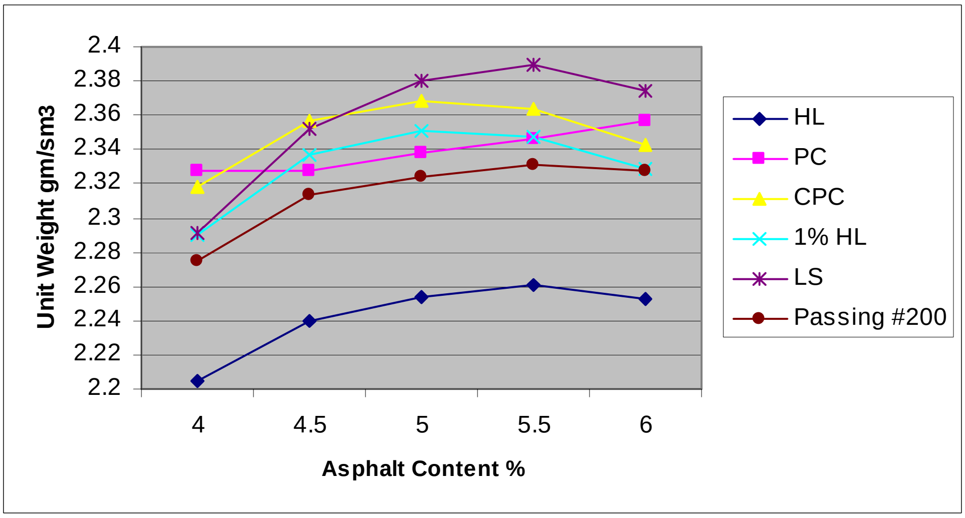

Figure (1) Unit Weight versus Asphalt Content.

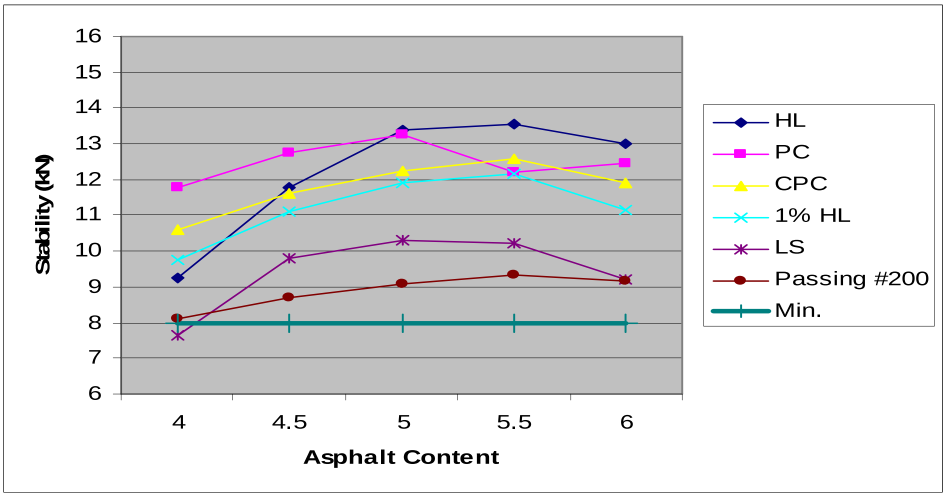

Figure (2) Marshall Stability versus Asphalt Content.

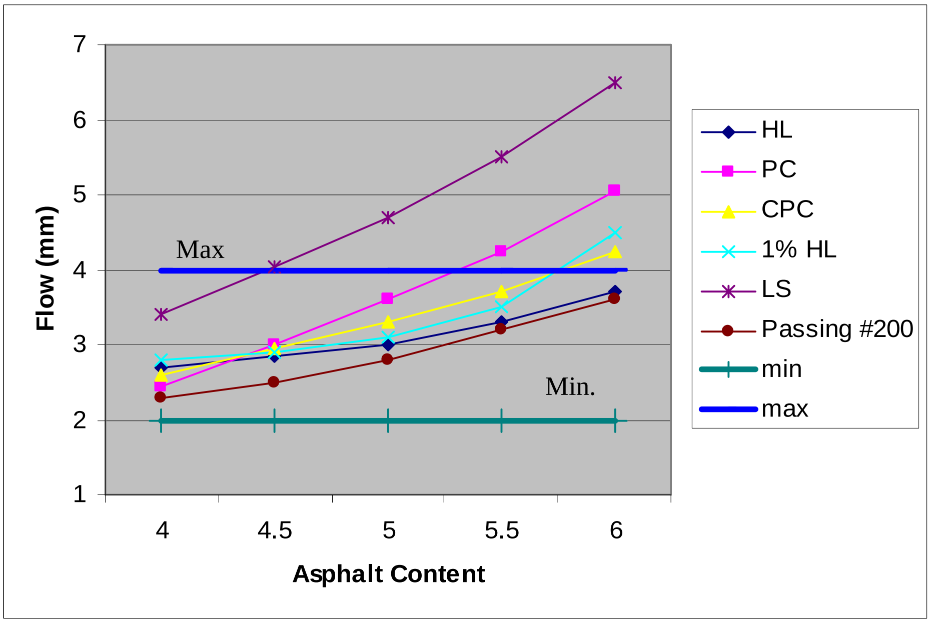

Figure (3) Marshall Flow versus Asphalt Content.

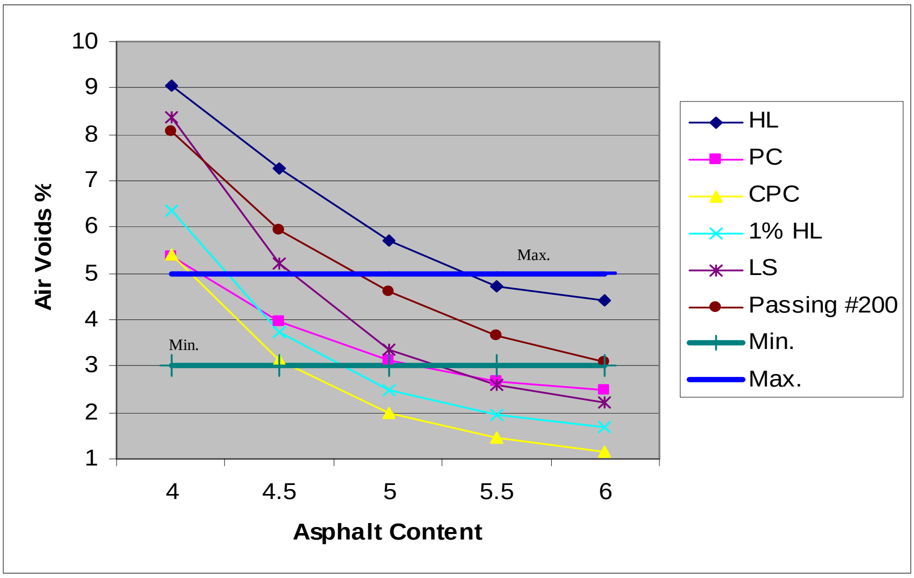

Figure (4) Voids in Total Mix versus Asphalt Content.

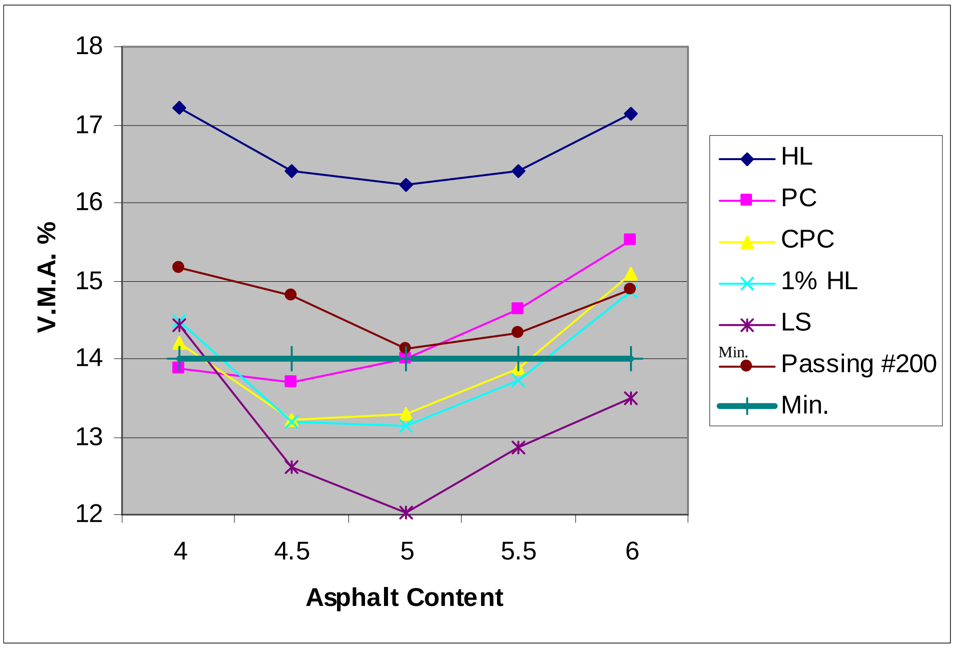

Figure (5) Voids in Mineral Aggregate versus Asphalt Content.

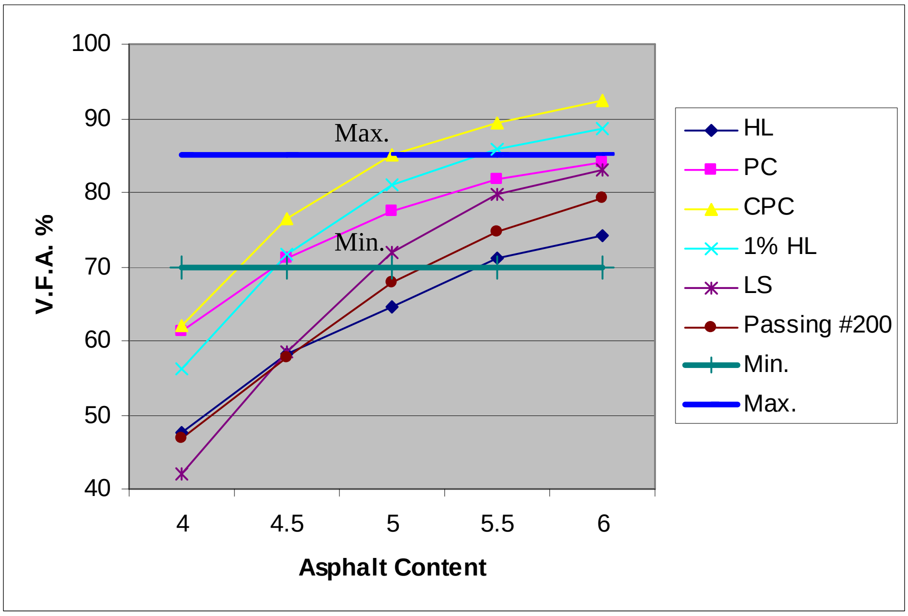

Figure (6) Voids Filled with Asphalt Versus Asphalt Content.

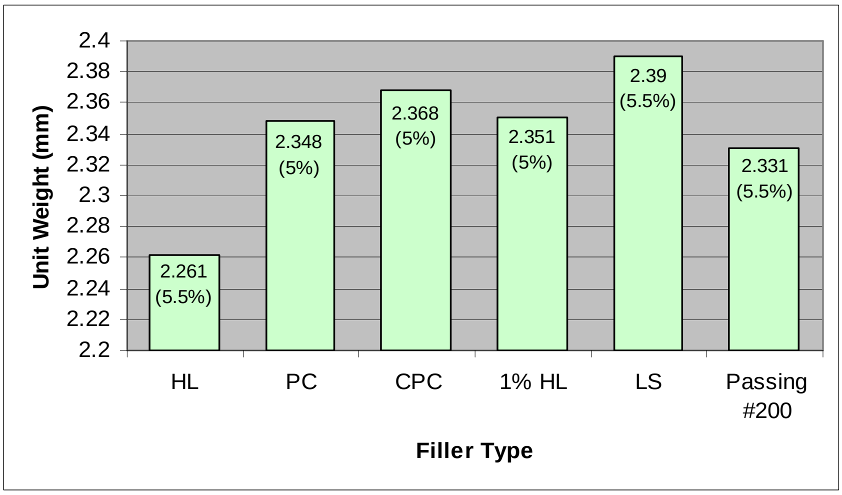

Figure (7) Maximum Unit Weight Versus Filler Type (number between parenthesis refers to binder content that provides the maximum unit weight).

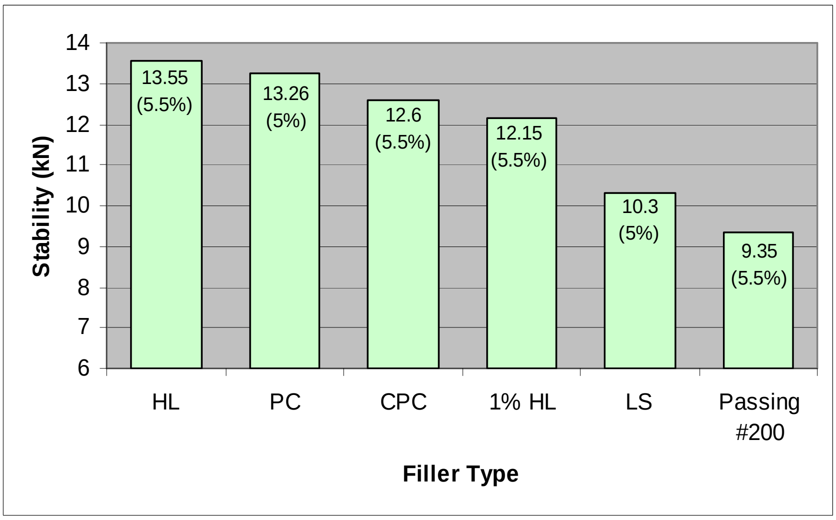

Figure (8) Maximum Stability Versus Filler Type (number between parenthesis refers to binder content that provides maximum stability)

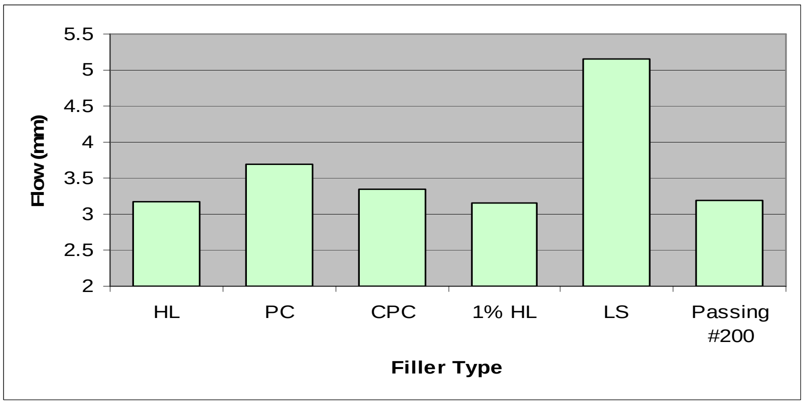

Figure (9) Median Flow Versus Filler Type.

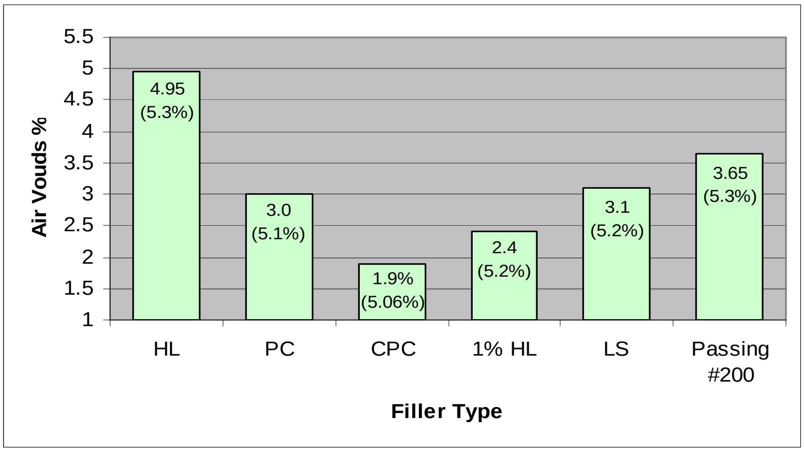

Figure (10) Median Voids in Total Mix Versus Filler Type (number between parenthesis refers to binder content that provides median voids in total mix).

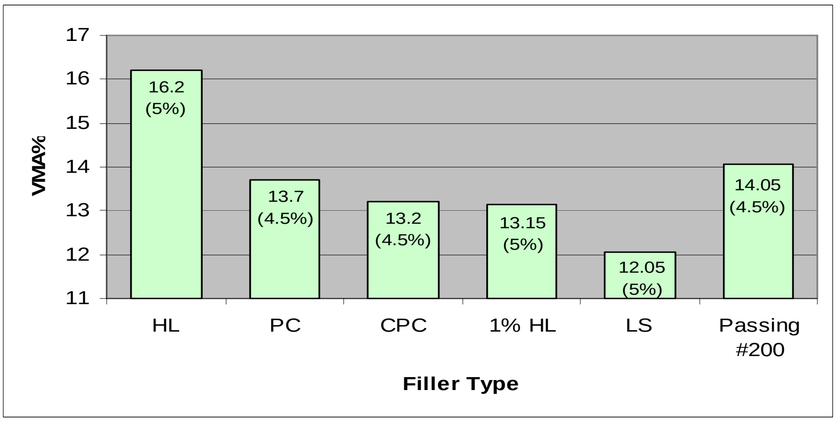

Figure (11) Minimum VMA Versus Filler Type (number between parenthesis refers to binder content that provides minimum VMA).