Effect of Lime Stone & Cement on the Mechanical Properties of Hot Mix Asphalt (HMA)

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Received: 22/5/2022 Accepted: 3/7/2022

ABSTRACT
Most of the roads in Iraq are paved using Hot Mix Asphalt (HMA) which is consisted of aggregates, asphalt cement and filler. In this study a laboratory investigation is conducted using two types of widely used fillers highly and locally available. Four different proportions of fillers are. Filler proportions used in this study are four proportion (i.e., 1.9%, 2.5%, 3.5%, and 4.5%) by total weight of aggregate for both types of fillers used. These proportions were blended using asphalt with penetration 40/50 and Performance Grade (PG70-10) using super-pave mix design methodology. The performance of bitumen binder with both types of filler was evaluated by: Penetration, Ductility, Softening Point, Penetration Index, Volumetric properties, Indirect Tensile Strength and Tensile Strength Ratio. The volumetric properties indicate that, the proportions of (1.9%, and 2.5%) for both type of filler are within the Super-pave criteria as the ITS increased with the increase of filler content and the highest TSR values for 2.5% Limestone dust is 90%, while for 3.5% Cement is 89.7%. Finally, it was concluded that the HMA is highly influenced by the amount and type of filler content.

Keywords:
HMA, Super-pave, Limestone, Cement, ITS, TSR

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1. INTRODUCTION
Highways and Roads are an important part of the transportation infrastructure network because they provide a means of transferring goods and people and are the backbone of a prosperous economy. More than 90% of road is paved with Hot Mix Pavement which is common due to many factors comfortable for ride. Cost effective in terms of construction and maintenance, faster construction time[1].

One of the most severe problems faced by road networks is the excessive frequency of traffic loads, and this problem increases with the presence of water that will penetrate into the components of the asphalt paving, which leads to stripping, disintegration, or moisture damage. It is a loss of adhesion between the asphalt and aggregates or a loss of cohesion between the asphalt binder of that mixture in the presence of the two most important factors, water and traffic loads. This failure may result in other defects in the layers of asphalt pavements such as rutting, fatigue, cracking, and potholes[2].

Using additives has been found to be one of the most efficient methods for increasing pavement durability and performance under heavy wheel loads. The use of hydrated lime as a mineral filler and anti-stripping material has raised more and more for field application, due to its availability, low cost and ease of manufacturing HMA compared to other additives such as polymers[3][4].

According to the theory of the filler “the filler serves to fill voids in the mineral aggregate and thereby create dense mix”[5]. According to this theory, each filler particle is independently coated with asphalt, and such coated particles, whether attached or discrete help to fill the voids in the asphalt mixture[5]. The moisture damage under traffic load, is greatly affected by the type and amount of filler[6].

When adding lime to the hot mix asphalt, it interacts with the aggregates, increasing the binding between the bitumen and the aggregate enhancing the resistance of HMA to rutting, fatigue and moisture damage improves the
The cement used in this research is Lenaz refinery/Irbil with penetration (40-50) and Performance Grade (PG70-10) the asphalt cement physical properties were tested according to ASTM and, AASHTO as shown in Table (1).

b. Aggregates Selection and Testing
The aggregate used is a crushed aggregates brought from (Qasurki Quarry) located at 15km south of Dohuk city. The crushed coarse and fine aggregates were sieved and recombined in the suitable proportion to match the Super-pave job mix specifications. All tests have been carried out on aggregates to assess the physical properties (i.e., Consensus and Source properties) as shown in Tables (2) and (3).

c. Filler Type Testing
Two types of filler are used in this work namely; Lime stone dust and Ordinary Portland Cement (delta) from and the test results are as shown in Table (4):

Table (1): The Properties of Asphalt Cement

| Property                       | Test condition         | Specification used | Result       | Super-Pave Criteria       |
|-------------------------------|------------------------|--------------------|--------------|---------------------------|
| Penetration                   | 25°C, 5sec             | ASTM D5            | 43           | 40-50                     |
| Ductility                     | 25°C, 5cm/min          | ASTM D-113         | 155          | >100                      |
| Softening point               | Ring & Ball            | ASTM D-36          | 53           |                           |
| Flash Point                   | open Cup               | ASTM D-92          | 277          | >232                      |
| Dynamic Shear                 | 10rad/s, passed @70°C, (1.6Hz) | AASHTO T315 | 1.345        | G*/SinD >1Kpa             |
| Rotational Viscosity          | Pa. Sec                | ASTM D4402         | 575@135°C    |                           |
| Bitumen Specific Gravity      | 25°C                   | D-70-97            | 1.03         |                           |
| Penetration                   | 25°C, 5sec             | ASTM D5            | 27           | ---                       |
| Ductility                     | 25°C, 5cm/min          | ASTM D-113         | 28           | ---                       |
| Softening point               | Ring & Ball            | ASTM D-36          | 60.5         |                           |
| Dynamic Shear                 | 10rad/s(1.6Hz), passed @0°C | AASHTO T315 | 5.165        | G*/SinD>2.2Kpa            |
| Test On RTFO+ PAV Residue :20 Hrs. @100°C |                     | AASHTO T315 | 3.80447      | G*/Sin <5Mpa              |

Dynamic Shear 10rad/s (1.6Hz), 30°C, AASHTO T315 3.80447 G*/Sin <5Mpa

Based on Test Result PG-Grading (70-10)

2.1 Asphalt Cement
SAMPLE PREPARATION AND TESTING

2. PREPARATION AND TESTING METHOD

3.1. Preparation of Asphalt Mixture Sample

The preparation of asphalt mixtures according to the super-pave requires compaction and mixing at a temperature at which the asphalt binder reaches Dynamic viscosity of (0.28 ±0.3, 0.17±0.02) pa/sec, by testing the asphalt binder using (Brookfield Rheometer) the temperature of mixing and compaction is (160-165) and ⁰C (150- 155) ⁰C respectively.[13]. The aggregate will be heated to the temperature of 160 ⁰C before mixing with the asphalt which is heated to the temperature as determined by the kinematic viscosity. After that, the asphalt cement is weighed in the required quantity and added to the heated aggregate and mixed to make sure that all the aggregate particles are coated with asphalt. After preparing the mixture to simulate what happen in the plant during the mixing process a short term of aging is (2 h @ 150⁰C) conduct.[12]. the compaction done using super-pave gyratory compaction (SGC) the vertical force is 600KPa and the rotation is 1.25, forces of SGC the tilt of the mold causes it to revolve at a pace of 30 rpm AASHTO T312. The number of Gyration chosen depending on the traffic level (Design EASL) in this study is more than 30million so the gyration number will be: N initial=9, N design=125, Nmax=205[13].

3.2. Selection of Aggregate Gradation

The mechanism of super-pave has been developed to use chart of power 0.45 prepared by the US Federal Highway Administration (FHWA), which uses a planning technique to control the distribution of the accumulated sizes of the mixtures. This chart is drawn using the ratio of the passing aggregate (the y-axis) and the size of the sieves in mm raised to the power of 0.45 (the x-axis) provided that it overlaps with the maximum density line and also include (control point, restricted zone). Therefore, in order to choose the design structure of the aggregate, sieve analysis of the aggregate was carried out according to the specification ASTM C136 with a maximum aggregate size 25mm and nominal aggregate size which 19mm. In this process five stockpiles (three type of coarse aggregate material, one crushed sand and lime stone dust)were sieved on different sieves and each gradient was isolated accordingly to the aggregate size 25mm and nominal aggregate size 19mm. The mechanism of super-pave has been developed to use chart of power 0.45 prepared by the US Federal Highway Administration (FHWA), which uses a planning technique to control the distribution of the accumulated sizes of the mixtures. This chart is drawn using the ratio of the passing aggregate (the y-axis) and the size of the sieves in mm raised to the power of 0.45 (the x-axis) provided that it overlaps with the maximum density line and also include (control point, restricted zone). Therefore, in order to choose the design structure of the aggregate, sieve analysis of the aggregate was carried out according to the specification ASTM C136 with a maximum aggregate size 25mm and nominal aggregate size which 19mm. In this process five stockpiles (three type of coarse aggregate material, one crushed sand and lime stone dust)were sieved on different sieves and each gradient was isolated accordingly to the sieve sizes, then three variable proportions were selected for each stock to obtain three different trial blendgradation, The Bulk specific gravities (Gsb) and Apparent specific gravity (Gsa) are determined for each trail, as shown table (5),Table (6) and Figure (1) below show aggregate gradation.

Table (6): Aggregate Specific Gravity Results

| Aggregate | 19 mm | 12.5 mm | 9.5 mm | Crushed Sand | Filler (Lime) |
|-----------|-------|---------|--------|--------------|--------------|
| Gsb       | 2.641 | 2.642   | 2.637  | 2.610        | 2.81         |
| Gse       | 2.688 | 2.703   | 2.710  | 2.753        | 2.80         |
Table(5) Gradation of Aggregate

| Blend  | Agg. 19mm | Agg. 12.5mm | Agg. 9.5mm | Crushed | Sand | Filler | Gradation of Blend | Gravitation of Blend2 | Super-pave Requirement |
|--------|-----------|-------------|------------|---------|------|--------|-------------------|----------------------|------------------------|
| Blend 1| 11.0%     | 19.1%       | 34.0%      | 34%     | 1.9% |        |                   |                      |                        |
| Blend 2| 9.0%      | 15.1%       | 35.0%      | 39%     | 1.9% |        |                   |                      |                        |
| Blend 3| 9.0%      | 10.0%       | 34.0%      | 45%     | 2.0% |        |                   |                      |                        |

| Sieve Size | Gradation Passing % | Min. | Max. | Min. | Max. | Min. | Max. |
|------------|---------------------|------|------|------|------|------|------|
| 50mm       | 100 100 100 100     |      |      |      |      |      |      |
| 37.5mm     | 100 100 100 100     |      |      |      |      |      |      |
| 25mm       | 100 100 100 100     | 95   | 96   | 90   | 100  |      |      |
| 19mm       | 100 100 100 100     | 42   | 85   |      |      |      |      |
| 12.5mm     | 0 42 100 100        | 82  | 85   |      |      |      |      |
| 9.5mm      | 0 2 75 100          | 67  | 73   |      |      |      |      |
| 4.75mm     | 0 0 9 99            | 39  | 44  |      |      |      |      |
| 2.36mm     | 0 0 1 69            | 29  | 33  |      |      |      |      |
| 1.18mm     | 0 0 0 43            | 17  | 21  |      |      |      |      |
| 0.6mm      | 0 0 0 27            | 11  | 13  |      |      |      |      |
| 0.3mm      | 0 0 0 16            | 7   | 9   |      |      |      |      |
| 0.075mm    | 0 0 0 4             | 3   | 3   |      |      |      |      |

For the purpose of knowing which of the three gradients can be chosen to design the asphalt mixture two samples of each trail will be mixed with 4.5% as initial asphalt content (Pbi)[12] and compacted using Super-pave Gyraoty Compaction, then volumetric properties for each blend estimated and determined N initial=9 and N design =125 In this study Blend Two have been chosen it shows best properties according to the super-pave specification (air voids<4%,VMA >13,VFA65-75,Dp0.8-1.2) as shown in Table (7), Then, at air voids equal 4% the volumetric properties is measured and evaluated again by the estimation of the effective binder content(Pbe) as shown in Table(8).

Table (7): Volumetric Properties of Trial Blends

| Blind | Va | VMA | VFA | Pbe | Dp | %Gmm @Nres | %Gmm @Nres |
|-------|----|-----|-----|-----|----|------------|------------|
| 1     | 3.20 | 12.69 | 74.7 | 4.06 | 0.79 | 87.1 | 96.8 |
| 2     | 4.02 | 13.14 | 69.4 | 3.92 | 0.87 | 86.9 | 96.0 |
| 3     | 4.37 | 13.44 | 67.5 | 3.92 | 0.96 | 86.9 | 95.6 |

Table(8): Estimation Volumetric properties at Air void=4 %

| Pbmax | VMA | VFA | Pbmax | Dpmax | %Gmm @Nres | %Gmm @Nres |
|-------|-----|-----|-------|-------|------------|------------|
| 4.18  | 12.7 | 68.7 | 3.2   | 0.85  | 86.30 | 96.1 |
| 4.51  | 13.1 | 69.5 | 3.9   | 0.87  | 86.90 | 96.5 |
| 4.65  | 13.3 | 70.1 | 4.0   | 0.93  | 87.20 | 96.7 |
3.3. Selection of Design Asphalt Content

The selection of design asphalt content (i.e., Design asphalt) included, preparing samples using different asphalt contents and estimate the volumetric characteristics of each sample then compare with the specified mix requirements in order to choose the Design asphalt binder content. Two samples of design gradation (Blend No.2) were mixed and compacted at four different asphalt content (Estimated asphalt 4.51%, 0.5% above, 0.5% below and 1% above) using(SGC).estimating the volumetric properties according to the super-pave specification(%Gmm@Nmin≤89,%Gmm@Ndes≥96)Table No.(9).With the relation of asphalt content Ac and AV%, VMA,VFA, and Dp drawn Figure (2) the asphalt content at air void 4% evaluated which is 4.7%. Finally, two samples are prepared and compacted at Nmax to check the

%Gmm@Nmax ≤ 98 according to super-pave

Figure 2 Superpave properties curves for hot mix design data criteria Table No.(10).

Table(9): Volumetric properties for different asphalt content @Ndes

| AC% | VA% | VMA% | VFA% | Dp% | %Gmm @Nmin | %Gmm @Ndes |
|-----|-----|------|------|-----|------------|------------|
| 4.01 | 5.78 | 13.63 | 57.62 | 1.00 | 84.90       | 94.20      |
| 4.51 | 4.47 | 13.54 | 66.95 | 0.87 | 85.80       | 95.50      |
| 5.01 | 3.26 | 13.55 | 75.90 | 0.77 | 86.60       | 96.70      |
| 5.51 | 2.09 | 13.60 | 84.62 | 0.69 | 87.50       | 97.90      |
3.4. Indirect Tensile Strength and Tensile Strength Ratio

This test was carried out according to the specification of AASHTO T-283, through which the performance of the asphalt mixture is evaluated for both tensile strength as well as resistance to moisture damage. The test conduct by dividing it into two groups, conditioned and un-conditioned samples (three specimens for each group).

Un-conditioned (dry) specimen immersed in water for 2h at temperature 25°C. The conditioned (wet) specimen should be saturated for (55-80)% and immersed in water at 60°C for 24h after being subjected to a freezing for 16h at (-18°C) then immersed in water again for 2h at temperature 25°C both groups tested by applying static Load at a rate of (50mm/min) .The Indirect Tensile Strength (ITS), and Tensile Strength Ratio (TSR) were obtained using the following Equation:

\[ ITS = \frac{P}{DT} \]  
\[ TSR = \frac{S_2}{S_1} \]

P = maximum load at failure, N  
D = Diameter of specimen, mm.  
T = Thickness of specimen, mm.  
S1= average ITS for unconditioned specimen.  
S2= average ITS for moisture conditioned specimen.

4. RESULT AND DISCUSSION

4.1 The effect of filler content on the rheological properties of the asphalt binder

The rheological properties of asphalt binder were studied by preparing five percentages of limestone dust and cement by weight of asphalt and compared them with the origin asphalt, which are (1.9%, 2.5%, 3.5%, and 4.5%). It is shown that, for lime stone and cement filler paste, the penetration decreases with the increase filler content. Ductility at 4.5% decreases for both lime stone and cement paste by 30.4% and 28.2%, meanwhile, the softening point increases with the increase of both filler contents as shown in Table (11).

4.2 Effect of Filler Content on Air Voids (AV) of Compacted Mixture.

The air voids are highly affected by the performance and durability of HMA’s as shown in Figure (4). When the air void content is too high, resulting mixture may be more permeable to air and water, causing moisture...
damage and age hardening. Increasing filler content will produce high stiff asphalt mastic (filler asphalt) which in turn gives more cohesive strength and binding force between coarse aggregate that make more easy to be compacted. Air voids content decreased by 45 percent as limestone filler content increases from control content up to 4.5 percent. Cement filler produced air voids content variation of 42.5 percent lower than 4.5 percent filler cement content HMA as shown in Figure (3). Lime stone filler produced harder HMA than cement mainly due to higher viscosity of the binder paste covering the mixture aggregates, but all the limestone contents are giving an acceptable air voids limits within SORB/2003 standards [14]. The same behavior is noticed for cement filler HMA, but with lower air void contents producing lower values of air void content values than limestone HMA as its filler paste have high viscosity which is more efficiently covering the aggregate surfaces. Lower penetration values given in Table (11) for limestone fillers than their values for cement-filler paste is the reason for that behavior. Air voids variation is usually the measure of HMA durability and external badly affecting factors like loads with the existence of moistening factors producing high water pressure to damage the binder film adhesion forces.

4.4 The Effect of Filler Content on Percent Voids in Mineral Aggregates (VMA)

The higher the VMA values in the dry aggregate, the more surface area there is for the asphalt film [15]. Most specifications specify that a particular minimum criterion for VMA based on the belief that the thicker the asphalt binder film on the aggregate particles, the more durability of the mix. Therefore, decreasing VMA to reduce asphalt content is actually counter-productive and damaging to pavement condition [15]. Figure (5), illustrates the effect of filler content on the VMA of HMA at different filler contents for super-pave prepared specimens. The increase of filler decreases the VMA for both types of fillers used in this study. Highest value of VMA was resulted at 1.9% and lowest one at 4.5% lime stone and cement filler contents respectively. Generally, limestone dust has a lower VMA when compared to the cement with the same content proportion. In comparison with the required percentage of the minimum specification VMA which is usually calculated as at least 13% for this HMA blend design, the results obtained were above the standard required which is (13) according to SORB/3 for 1.9% and 2.5% for both type of filler which produced highly stiff HMA mixtures.

4.3 The Effect of Filler Content on the Percentage of Voids Filled with Asphalt (VFA)

Voids filled with asphalt characteristic is significant not just as a measure of relative durability, but also because it has a strong relation with density ratio. When the VFA is very low, there will be insufficient asphalt to offer durability, over-density under traffic, and bleeding of the
asphalt binder will be resulted[15]. The effect of different filler types in various proportions on the VFA of HMA is shown in Figure (6), which indicates that the VFA is increasing with decrease of filler content proportion for limestone dust and cement filler.

![Figure (6): Effect of Filler Content on the Voids in Mineral Aggregate](image6)

### 4.4 Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR)

Environmental factors such as, temperature may have a profound impact on the durability of asphalt pavements and have a negative impact on the mechanical behavior of the HMA in the future after being subjected to loads in the same conditions. Moisture sensitivity is evaluated by conducting an Indirect Tensile Strength Test (ITS), from which, the tensile strength ratio (TSR) could be calculated. Figure (7) shows that, there is an increase in the ITS with the increase of filler content for both Limestone dust and ordinary Portland cement fillers in both cases of unconditioned and conditioned before loading in the testing machine. It is shown that, the highest value of ITS for unconditioned and conditioned is at 4.5% filler content with 1174Pa, 1225 and 1025.7, 997.8 Pa respectively for Limestone dust and Portland cement fillers. Regarding the Tensile Strength Ratio (TSR), where the percentages exceeded 80% for all filler proportions for both filler type limestone dust and cement due to higher adhesion between the asphalt binder and the aggregate, which leads to less probability to have stripping between binder paste and aggregate surfaces. As shown in Figure (8), the highest value were 90 percent at 2.5 percent Limestone dust content, while the highest value for Portland cement was 89.7 percent at 3.5 percent were 90 percent at 2.5 percent Limestone dust content, while the highest value for Portland cement was 89.7 percent at 3.5 percent.

![Figure (7) The Effect of Filler Content on the Indirect Tensile Strength test of (A) Unconditioned (B) Conditioned](image7)
more than 80 percent its increase by 5.6% for 2.5% limestone dust while increase by 11.6% for 3.5% cement indicating that filler content improved moisture resistance of hot mix asphalt under wheel load applications by 17.6% and 39.7% for conditioned.

It is recommended, same study could be conducted on limestone and back house dust filler to show and compare the behavior of each one of them for better application in the real construction field.

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تأثير الحجر الجيري والأسمنت على الخواص الميكانيكية للخلطة الإسفلتية الساخنة

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الملخص

تتم رصف معظم الطرق في العراق باستخدام خليط الإسفلت الساخن الذي يتكون من الركام الإسفلت والفلر. في هذه الدراسة، تم إجراء دراسة باستخدام نموذج الخليط الساخن، حسب نموذج الدورة PG70-10*، لمعرفة التأثير المحتمل لوضع محتوى الحشو من مادة الصرف والفلر، والذي يعتمد على نسبة الحشو للكرمل، وذلك باستخدام نظام الاداء الفائق Super-pave. تم التحقق من التركيب النسب محتوى الخليط الساخن حسب المستخدمة في هذه الدراسة، حيث تشير الخواص الميكانيكية إلى أن نسبة 2.5% من محتوى الخليط الساخن، حيث زادت نسبة قوة الضغط TSRC من 7.0% إلى 88.7%، بينما نسبة المحتوى من إجمالي وزن الركام لكل نوع من المواد الشاذ ينخفض بشكل كبير. نتائج هذه الدراسة تشير إلى أن الخليط الساخن يتأثر بشكل كبير بكمية ونوع محتوى الصرف والفلر.

الكلمات الدالة:
الخلطة الإسفلتية، نظام الاداء الفائق، الحجر الجيري، نسبة قوة الضغط. TSRC.