American Journal of Civil Engineering and Architecture, 2019, Vol. 7, No. 4, 157-166
Available online at http://pubs.sciepub.com/ajcea/7/4/2
Published by Science and Education Publishing
DOI:10.12691/ajcea-7-4-2

Laboratory Investigation on the Likely Usage of Sub-base Course Dust: An Alternative Filler Material Ingredient for Marshall Design Mix

Woyesa Ararsa, Emer Tucay Quezon*, Abdin Bedada, Eyob Mekonnen, Dumesa Gudissa

Construction Technology & Management Department, and Civil Engineering Department, Institute of Technology, Awaro Campus, Ambo University, Ambo City, Oromia Region, Ethiopia, North-East, Africa
*Corresponding author: quezonet09@gmail.com

Received July 02, 2019; Revised August 04, 2019; Accepted August 08, 2019

Abstract Construction of road asphalt pavement is always considered to be one of the very few challenging endeavors in implementing projects due to the type and content of the filler material ingredient and bitumen. This research study investigated the likely usage of natural Sub-base Course Dust (SCD) as alternative filler material and its effect in the Hot Mix Asphalt (HMA) through laboratory tests. There were forty-eight samples prepared according to ASTM D1559, of which out of fifteen samples used to determine the optimum bitumen content, while the remaining samples utilized to determine the effects of adding varying percentages of SCD to the asphalt mix. Five different bitumen percent contents applied, starting from 4%, 4.5%, 5%, 5.5% & 6%. The aggregate mixtures mixed "with" and "without" Sub-base Course Dust (SCD) filler ingredients evaluated the Marshall properties of Hot Mix Asphalt (HMA). Likewise, four different contents of Sub-base Course Dust (SCD) filler materials considered, ranging from 2% to 8%, with an increment of 1%. On the other hand, the control mix established with 2% Hydrated Lime (HL), 2% Ordinary Portland Cement (OPC), and 4% marble dust ingredients. The Job mix formula used to obtain the percentage of material proportion for the laboratory experiment. The aggregate ratio applied for "without" filler in 3/4 size of 26%, 3/8 size of 23%, and fine of 51%, while for the aggregates "with" Sub-base Course Dust (SCD) filler, 3/4 size of 26%, 3/8 size of 22%, fine sand of 46%, and mineral filler of 6%. Laboratory test results indicated the Optimum Bitumen Content (OBC) of about 5.1% of the total Hot Mix Asphalt (HMA), and the optimum percentage of Sub-base Course Dust (SCD) indicated 6%. The Marshall properties of the Hot Mix Asphalt (HMA), when the 6% Sub-base Course Dust (SCD) filler ingredient applied, it resulted in high stability, low flow, low Voids in Mineral Aggregates (VMA), low Voids Filled with Binder (VFB), and Low Air Voids. These results complied with the Standard Specifications. Therefore, Sub-base Course Dust (SCD) filler ingredient can likely be used as an alternative filler material in Hot Mix Asphalt (HMA) with an optimum filler content of 6%.

Keywords: *aggregates, Hot Mix Asphalt, marble dust, marshall mix design, optimum filler content, optimum bitumen content, sub-base course dust*

Cite This Article: Woyesa Ararsa, Emer Tucay Quezon, Abdin Bedada, Eyob Mekonnen, and Dumesa Gudissa, “Laboratory Investigation on the Likely Usage of Sub-base Course Dust: An Alternative Filler Material Ingredient for Marshall Design Mix.” *American Journal of Civil Engineering and Architecture*, vol. 7, no. 4 (2019): 157-166. doi: 10.12691/ajcea-7-4-2.

1. Introduction

A project planning, design, construction, and maintenance of road pavement in Ethiopia necessitate a significant amount of excellent quality pavement materials. The increasing traffic demands require a better quality for paving application. The development and usage of the modified asphalt mix should meet the needs of the local people.

One of which, asphalt modification can be realized primarily through polymer modification in the asphalt concrete mix. However, the method is expensive due to the increasing prices of raw polymer materials, requiring skilled personnel, and specialized equipment to be used. In the other application, asphalt mix modification could be done by replacing the standard filler such as lime, cement, and other suitable materials [1].

Road pavements are mainly categorized into two types, such as rigid and flexible. The rigid pavement is composed of a Portland cement concrete surface layer, while the flexible pavement constructed with bituminous materials and other ingredients. Asphalt concrete is a mixture of aggregate, bitumen, bitumen, and filler in a different relative proportion. In the last seventeen years (1997-2014 G.C) in Ethiopia, the total length of rigid pavement constructed was only 2.3 kilometers, while about 99.9% or 12,640 kilometers are flexible pavements [2]. These flexible pavements are exposed to several factors, mainly heavy axle load applied, high traffic volume, and excessive moisture that influences the pavement layers at intermittent sections [3].

Some road sections usually displayed excessive failures at an early stage of the pavement design life. A significant step in the improvement of the current performance of pavement emanates with modification of the mix design. The strength, amount, and stability of asphalt mixtures would have influenced by several features together with a gradation of aggregates, types, and amount of filler materials. The mechanical properties of asphalt concrete depend on the properties of fillers and bitumen. Modifications of asphalt paving materials which have high-quality additives are quite costly for the production of bituminous mixtures of road construction. To reduce the impact of this problem is by considering the application of natural mixture ingredients [4].

According to Kandhal, et al., the properties of mineral fillers, especially the material passing 0.075mm (No. 200) sieve has a significant effect on the performance of asphalt paving mixture in terms of deformation, fatigue cracking and moisture susceptibility. Mineral fillers initially have been included to dense-graded HMA paving mixtures fill the voids in the aggregate ingredients and to reduce the voids in the mix [5].

On the other hand, Asi Ibrahim and Assa'ad Abdullah studied fillers that are used in the asphalt mixture to affect the mix design, especially the optimum bitumen content. The term filler is often utilized loosely to designate a material with a particle size distribution smaller than No. 200 sieve. The filler materials theory assumes that "the filler serves to fill voids in the mineral aggregate and thereby create the dense mix." Filler particles are beneficial because of increased resistance to displacement resulting from the broad area of contact between particles. It's believed that fillers increase the required compaction effort of specimens to the same volume or air void content. The function of mineral filler is mainly to stiffen the binder [6].

Some conventional filler materials such as cement, lime, granite, and marble powders are generally used as filler in asphalt concrete mixture in another world. These are costly and use for another purpose more effectively. From the economic point of view, the researchers sought to investigate the likely usage of sub-base course dust as an alternative filler material ingredient in the hot asphalt concrete mixture. The results obtained, compared with the conventional fillers and the standard specifications [7].

Besides, the research evaluated the effects of likely usage of sub-base dust filler on the Marshall properties of the Hot Mix Asphalt and determined the optimum proportion that could be used as an alternative filler material.

A filler material had been traditionally used in asphalt mixtures to fill the voids between the aggregate particles [8]. According to Bahia et al., the influence of different types of fillers on the properties of asphalt concrete mixture varies with the particle size, shape, surface area, surface texture and other properties [9]. In Ethiopia, materials such as fine sand, cement, marble dust, hydrated lime, and crushed stone, are used in asphalt mix as filler for pavement construction. One of the main issues in the construction of asphalt pavement is how to get a sufficient amount of filler from any source, including its high cost. Asphalt Institute established a maximum percent content of Ordinary Portland Cement and hydrated lime of 2% separately to improve the adhesion properties of the aggregates. However, this quantity is not sufficient to achieve the required grade requirements. Also, marble dust used, which is a waste by-product of a marble manufacturing plant.

The research study conducted to seek a good quality filler material ingredient that would possess less expensive and locally available for asphalt concrete mix production. It was with this purpose; the researchers explored the likely usage of other natural sub-base course dust ingredient to be utilized as non-conventional fillers in the HMA for surfacing layer of highway pavement construction. Precisely, to determine the physical properties of sub-base course dust filler in HMA, its effects of the dust filler on the Marshall parameters, and the optimum content of the dust filler.

2. Materials and Research Methods

2.1. Materials

The raw materials used for the laboratory experiment obtained around Addis Ababa:

a. Asphalt Cement (AC) of 85-100 Penetration Grade

b. Crushed aggregates: Coarse, intermediate, and fine aggregates

c. Screened natural sub-base course grounded to obtain the powder or dust.

2.2. Tests and Materials Preparation

2.2.1. Mineral Aggregates

Generally, aggregate accounted for 92% to 96% of HMA by weight. Locally available aggregates were having a specific gravity of 2.72 and 2.59 for coarse and fine aggregates, respectively. ERA and AASHTO standard specifications applied for the aggregate gradation in the laboratory experiments.

2.2.2. Physical Properties of Aggregates

The laboratory tests performed to evaluate the physical properties of the aggregates. Gradation tests conducted to determine the size distribution for each aggregate type. It is one of the essential characteristics in determining how an HMA mixture that performs as a pavement material. Aggregate gradation influences almost every valuable HMA property, including stiffness, stability, workability, durability, permeability, fatigue resistance, skid resistance, and resistance to moisture damage. The gradation, with a combination of aggregate sizes, is one of the critical factors in studying the performance behavior of asphalt mixes. The test conducted according to specification stipulated in ASTM C136.

2.2.3. Marshall Test Method

Marshall Stability test utilized in this research to determine the optimum binder content and evaluating the specimens of natural subbase dust filler. This method covered the quantification of the resistance to plastic flow of cylindrical specimens of asphalt paving mixture, loaded on the lateral surface using the Marshall apparatus according to ASTM D1559-89. The prepared mix placed in a pre-heated mold of 101.6mmØ x 63.5mm in height. Each face of the specimen compacted with a total number of 75 blows. The specimens left to cool at room temperature for 24 hours.

Marshall stability and flow tests performed for each specimen. The cylindrical specimen placed in a water bath at 60ºC for 30 to 40 minutes. The specimen compressed on the lateral surface at a constant rate of 50.8mm/min until the maximum load at failure had reached. Then the maximum load resistance and the corresponding flow values recorded. Three specimens for each combination prepared, and the average results reported. The bulk specific gravity, density, air voids in a total mix, and voids filled with bitumen percentage determined for each specimen.

2.2.4. Optimum Binder Content

The Marshall test utilized to determine the optimum binder content. Five portions of bitumen examined to determine the best percentage of asphalt for the aggregates used, from 4% to 6%, with 0.50% increment by weight of the mix considering three samples for each proportion. The optimum binder content found equal to 5.1% by weight of the total mixed ingredients, which was calculated as the average of binder content values corresponding the maximum stability, maximum density and median percent of air voids.

2.2.5. Optimum Natural Sub-base Dust Content

All asphalt mixtures prepared with the same binder content of 5.1%. The satisfactory percentage of natural subbase dust that can be used as filler in the mix determined by investigating four portions of screened and pulverized natural sub-base dust filler with 2% to 8% by weight, considering 2% increment. Hereunder, the procedure in preparing the natural sub-base dust filler specimens based on the Marshall method designated in ASTM D1559-89:

a. Natural sub-base material screened, pulverized, and then sieved.

b) The gradation uses natural SCD filler and checked for uniformity with the grain size distribution of other conventional fillers.

c) Four percentages from 2% to 8% by weight of the total aggregate of natural SCD with 2% increment investigated the three samples for each proportion.

d) Natural SCD filler mixed with other aggregates using the percentages above, then heated to a temperature of 145°C before mixing with asphalt cement.

e) Before mixing with aggregates, asphalt was heated up to 145°C. Preheated asphalt avoided, and excess heated bitumen was disposed to prevent variability in the asphalt properties.

f) The required amount of asphalt was added to the heated aggregate and mixed thoroughly for at least 3-minutes until a homogenous mix obtained.

g) The standard Marshall molds heated in the Oven up to 130°C, then the hot mix placed in the mold. Each face of the specimen compacted with 75 blows.

2.2.6. Mixture Characteristics and Behavior

Specimens for asphalt mix developed in the laboratory to determine its probable performance in a pavement structure. It focused on four characteristics of the mixture and their influence on the behavior of the mix. These characteristics were Density, Air Void, Void in the mineral aggregate, and Asphalt content. Likewise, the standard procedure for finding the bulk specific gravity of compacted asphalt concrete involved weighing the specimen in air and water.

The following formulae used for calculating bulk specific gravity of a saturated surface-dry specimen:

$$Gmb = \left(\frac{A}{B - C} \right) \tag{1}$$

Where;
G_{mb}= Bulk specific gravity of compacted specimen
A = Mass of the dry sample in air, g
B = Mass of the saturated-surface-dry sample in air, g
C = Mass of the sample in water, g.

2.2.6.1. Air Voids

A certain amount of air voids is necessary for the HMA produced to allow for a slight amount of compaction under traffic and a small amount of asphalt expansion due to temperature increased. The allowable percentage of air voids in the laboratory test of specimens from 3% - 5%. The durability of asphalt pavement is a function of the air void content. Hence, designing and maintaining proper air void content in HMA is essential for the performance of the pavement. Air void content is determined from the mixture bulk and theoretical maximum specific gravity:

$$V_a = 100\left[1 - \left[\frac{G_{mb}}{G_{mm}}\right]\right] \tag{2}$$

Where;
V_a = Air void content, volume %
G_{mb} = Bulk specific gravity value of the compacted mixture.
G_{mm} = Theoretical maximum specific gravity of the loose mix.

2.2.6.2. Voids in Mineral Aggregate (VMA)

The VMA represented the void space that is free to accommodate the sufficient volume of asphalt (except the portion lost by absorption of the aggregate) and the volume of air voids in the mixture. Hence, the specific minimum requirements for VMA recommended and specified as a function of the aggregate size. The minimum VMA needed to achieve an adequate asphalt film thickness, which resulted in durable asphalt pavement. While increasing the density of the gradation of the aggregates to a point below the minimum VMA values leads to thin films of asphalt and a low durability mix.

$$\mathbf{VMA} = \left(\mathbf{V_a} - \mathbf{V_{be}}\right) \tag{3}$$

Where;
V_a = Air void content, % by a total mixture volume
V_{be} = Effective binder content, % by a total mixture volume.

2.2.6.3. Binder Content

Binder content is the essential characteristics of the asphalt pavement mixture. The use of the proper amount of binder is a must for excellent performance in the asphalt concrete. The total asphalt content *(P_b)* by volume of mixture computed as the percentage of the binder by the total mix mass of asphalt concrete:

$$P_b = 100\left[\frac{M_b}{M_s + M_b}\right] \quad (4)$$

Where;
M_b = Mass of binder in the specimen
M_s = Mass of aggregate in the specimen

The total asphalt binder contents *(V_b)* by volume of concrete is calculated as a percentage of total mix volume using the following formula:

$$V_b = \left[P_b * \frac{G_{mb}}{G_b}\right] \quad (5)$$

Where;
G_{mb} = Bulk specific gravity of the mixture mass
G_b =Specific gravity of asphalt binder.

The absorbed asphalt binder contents *(V_{ba})* by volume is also calculated as a percentage of total mix volume.

$$V_{ba} = G_{mb}\left[\left(\frac{P_b}{G_b}\right) + \left(\frac{P_s}{G_{sb}}\right) - \left(\frac{100}{G_{mm}}\right)\right] \quad (6)$$

Where;
G_{mb}= Bulk specific gravity of the mixture mass
P_b= Total asphalt binder contents, % mix mass
G_b= Specific gravity of the asphalt binder
P_s = Total aggregates contents, % mix mass=100 – P_b
G_{sb}= Average bulk specific gravity for the aggregates mixed
G_{mm}= Maximum specific gravity of the mixture mass

The effective asphalt by volume*(Vbe)* found by subtracting the absorbed asphalt content from the total asphalt content of the mixture:

$$V_{be} = (V_b - V_{ba}) \quad (7)$$

Where;
V_b= Total asphalt binder contents, % mixture volume
V_{ba}, = Absorbed asphalt contents, % total mixture volume.

The effective and absorbed asphalt binder contents computed as a percentage by weight, once the volume percentage has been calculated:

$$P_{ba} = P_b - P_{be} \quad (8)$$

$$P_{be} = P_b\left[\frac{V_{be}}{V_b}\right] \quad (9)$$

Where;
P_{be} = Effective asphalt binder content, % of the total mass
P_b = Asphalt binder content, % of the total mass
V_{be} = Effective asphalt binder contents, % total mixture volume
V_b = Asphalt binder contents, % total mixture volume
P_{ba} = Absorbed asphalt binder content, % total mixture mass.

2.2.6.4. Voids Filled with Asphalt

The voids filled with asphalt (VFA) are the percentages of inter-granular void space between the aggregate particles which contained or filled with asphalt. The VFA included ensuring the effective asphalt part of the VMA in a mix was not too little (i.e., dry, poor durability) or too much (i.e., wet, unstable). The VFA is the effective binder contents expressed as a percentage of the VMA:

$$VFA = 100\left[VMA - \frac{V_a}{VMA}\right] \quad (10)$$

Where;
VMA =Voids in the mineral aggregates, % total mixture volume
V_a = Air void contents, % total mixture volume.

2.3. Test Procedure

From the Marshall mix design method, all compacted specimens are subjected to Bulk Specific gravity determination. Stability, and flow tests, Density and Void analysis.

2.3.1. Marshall Testing Machine

A compression testing device designed to apply loads to test specimens through cylindrical segment testing heads (i.e., the inside radius of curvature of 51mm at a constant rate of vertical strain of 51mm per minute). This machine equipped with a calibrated proving ring for determining the applied load test, a Marshall stability testing head for use in testing the specimen and a Marshall flow meter for determining the amount of strain at the maximum load in the test.

2.3.2. Water Bath

A water bath puddle used at least 150mm deep and thermostatically controlled of 60°C ± 1°C temperature. The tank provided a perforated bottom or equipped with a shelf suspending specimens at least 50mm.

3. Results and Discussion

3.1. General

There were forty-four sets of bituminous concrete mixtures using different types of mineral fillers evaluated using the Marshal Mix design method. These mixtures prepared using crushed stone aggregates, and natural SCD fillers with varying contents of asphalt binder. The total mix and their effect on Marshal properties evaluated according to the different parameters.

3.2. Aggregate Gradation for Mix Design

The following gradation sizes obtained according to ERA specifications: Coarse aggregate = G-1 ¾ inches, Intermediate aggregate of G-2= 3/8 inch, Fine aggregate of G-3, and Mineral filler of G-4. Likewise, the blending proportion of the mixture without SCD filler: G-1 = 32%, G-2 = 23% and G-3, = 45% by weight of the total mixture.

Results indicated that Aggregate Gradation and mixing with natural Sub-base Course Dust (SCD) as filler material satisfied the grading requirements of the upper and lower limit. A job mix of G-4 = 6% of SCD mixed with the aggregates at a proportion of G-1 = 26%, G-2 = 22% and G-3 = 46% resulted from proper mixing for the Marshall mix design.

3.2.1. Asphalt Binder Test Results

A series of laboratory tests, including penetration, specific gravity, softening point, flash point, and solubility performed for the characteristic properties of penetration grade asphalt. The results of the laboratory are shown in Table 1, which satisfied with the requirement of ERA specifications.

3.3. Sub-base Course Dust (SCD) Filler

The filler used in this research study was screened and pulverized natural sub-base course material obtained from the quarry site. The physical properties affecting the bituminous mixture such as gradation parameters and plasticity index determined as shown in Table 3.

3.4. Determination of Optimum Bitumen Content

Marshall test was used to examine the asphalt mixture specimens with percentages of bitumen content from 4%, 4.5%, 5%, 5.5%, and 6%, and 5.1% optimum bitumen content obtained.

3.4.1. Marshall Test Results

Marshall test results of the mixtures with different binder content presented in Table 4. The relationships between binder content and the mixture properties such as Stability, Flow, VFB, VMA, VA, and Bulk Density showed in the following figures. Sets of Forty-four samples, each weighing 1.2kgs prepared using five different bitumen contents of 4%, 4.5%, 5%, 5.5% and 6% of the total weight to determine the optimum bitumen content. The process of measuring the stability values from the standard thickness was converted to an equivalent 63.5mm value using conversion factors.

Table 1. Physical Properties of Bitumen Used

Test Description	**Unit**	**Test Method**	**Test Result**	**Specification Limit**
Penetration @25°C	1/10mm	ASTM D5-06	90	85 – 100
Specific gravity @25°C	kg/cm^3	ASTM D70	1023	1020
Ductility @25 °C	cm	ASTM D113-86	100+	100+
Solubility	%	ASTM D2042	99.6	Min 99
Softening Point	^0C	ASTM D36	46.4	42 – 52
Fire Point	^0C	ASTM D92-90	23	Max 100
Flash Point	^0C	ASTM D92-90	562	Min 232

Table 2. Filler Materials Used for Control Mix

No.	**Filler Materials**	**Test Method**	**Specific Gravity**
1	Hydrated Lime	ASTM D854	2.15
2	OPC Cement	ASTM D854	3.5
3	Marble Dust	ASTM D854	2.69

Table 31. Laboratory Test Result for SCD Filler

No.	Test Description	**Test Method**		**Result**	Specification (ERA Manual 2002)
		ASTM	**AASHTO**		
1	Specific gravity (kg/m^3)	**D 854 or C88**	T 100 or 104	2.683	N/A
2	PI, (Plastic Index)	**D 423 or 424**	**T 89 or T 90**	**NP**	**Max 4**

Table 4. Marshall Test Result for Mixes without Filler

Marshall properties of bituminous mixtures					
Description	Aggregate Size				
	G1, 3/4mm	G2, 3/8mm	G3, Fine	G4, Filler	Value
Blending proportion, %	26	23	51	0	100
Bulk Specific Gravity per specimen	2.59	2.62	2.79	0	
Bulk Specific Gravity, Total Aggregate, *Gsb*					2.696

Table 5. Marshall Test Result for Mixes with 6% SCD Filler

Marshall properties of bituminous mixtures					
Description	Aggregate Size				
	G1, 3/4mm	G2, 3/8mm	G3, Fine	G4, Filler	Value
Blending proportion, %	26	22	46	6	100
Bulk Specific Gravity of each	2.59	2.62	2.79	2.68	
Bulk Specific Gravity, Total Aggregate, *Gsb*					2.691

Table 6. Summary of Marshall Test Results

AC content (%)	Unit Wt (Mg/m³)		Air Void, (%)		VMA (%)		VFB (%)		Corrected Stability (KN)		Flow (mm)	
	A	B	A	B	A	B	A	B	A	B	A	B
4	2.308	2.285	10.2	11.0	17.82	18.47	42.7	40.5	12.30	17.7	4.17	3.57
4.5	2.338	2.287	7.4	10.7	17.18	18.83	56.9	43.2	12.46	12.67	3.63	3.82
5	2.359	2.305	5.7	7.7	16.86	18.62	66.2	58.6	11.10	12.63	3.68	4.17
5.5	2.396	2.342	3.0	5.5	16.02	17.76	81.3	69.0	9.11	11.96	3.94	3.84
6	2.381	2.347	3.4	4.1	16.99	18.0	80.0	77.2	11.99	9.71	5.03	4.60

Where A: - Mixture Blended "without" SCD Filler, B: - Mixture Blended "with" SCD Filler.

A summary of the Marshall test results "without" and "with" SCD filler ingredients presented in Table 6.

3.4.2. Marshall Stability

Stability of asphalt mix is a measure of the mass viscosity of the aggregate-asphalt. It affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement. The maximum load required to produce a failure of the sample when the load is applied at a constant rate of 50mm/min, which provided the stability of the specimen. The addition of SCD filler ingredient in the asphalt mix would reduce the deformation due to high temperatures, especially during its early life when it is most susceptible to pavement rutting. It means, the filler provided the HMA less sensitive to moisture effects by improving the aggregate asphalt bond. The use of filler in the hot asphalt mix has resulted in a void and asphalt content values to decrease. So, decreasing of asphalt content by adding natural sub-base filler resulted in high stability by avoiding rutting, flushing, and bleeding effects of the pavement. From Figure 1, it indicated the maximum stability of the asphalt mix of 13.9KN at 5.1% bitumen content.

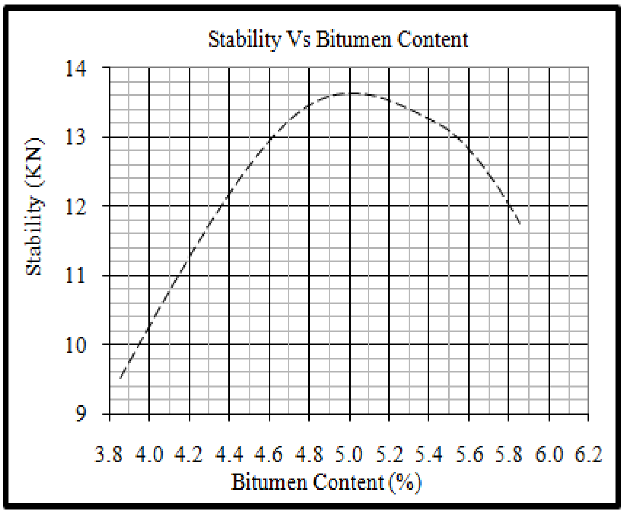

Figure 1. Stability Vs. Bitumen Content

In Figure 2 below indicated the unit weight of 2.375% at 5.1% bitumen content.

Likewise, Figure 3 shows the relationship of Voids in Mineral aggregates (VMA) and bitumen content. From the graph, the VMA is 16.75%, at 5.1% bitumen content.

3.4.3. Voids Filled with Asphalt

The voids filled with asphalt (VFA) provided the percentage of the inter-granular void space between the aggregate particles. From Figure 4, it could be noticed that the VFB increases gradually as bitumen content increases. It was due to the rise of voids percentage filled with bitumen in the asphalt mix. The VFA represents the volume of effective bitumen content in the mixture. It is inversely related to air voids; hence, as air voids decrease, the VFA increases. But from the result, it can be observed that the addition of SCD filler to the bituminous mixture changed the trend opposite, resulting in a decrease of both air void and asphalt content. Figure 4 shows the results of VFB at different bitumen contents. The VFA indicated 70.5%, at 5.1% bitumen content.

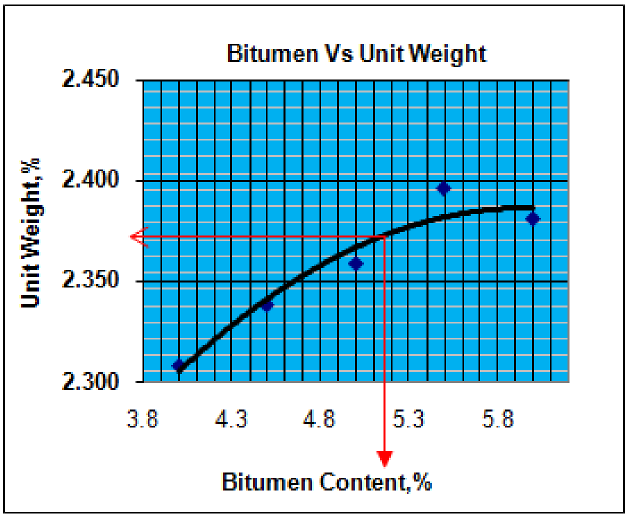

Figure 2. Unit Weight Vs. Bitumen Content

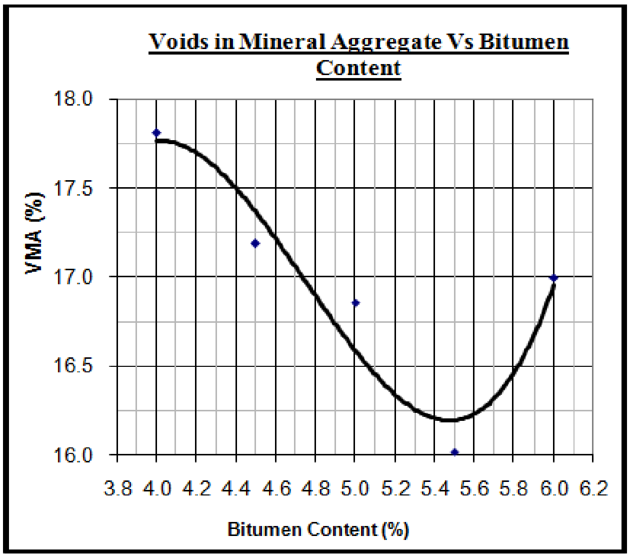

Figure 3. VMA Vs. Bitumen Content

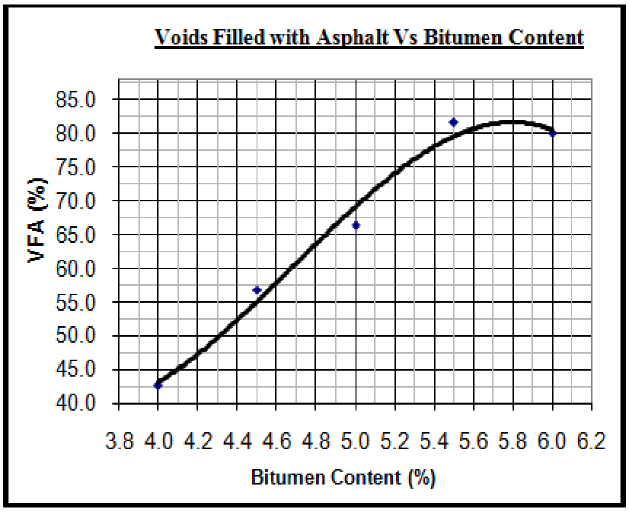

Figure 4. VFA Vs. Bitumen Content

3.4.4. Air Voids Content

The air voids (VA) represent the total volume of the small air pockets between the aggregate coated with asphalt throughout a compacted paving mixture. From Figure 5, it can be noticed that the air voids content gradually decreases with increasing the bitumen content, due to the increase of voids percentage filled with bitumen in the asphalt mix. The VA value was 5.0%, at 5.1% bitumen content.

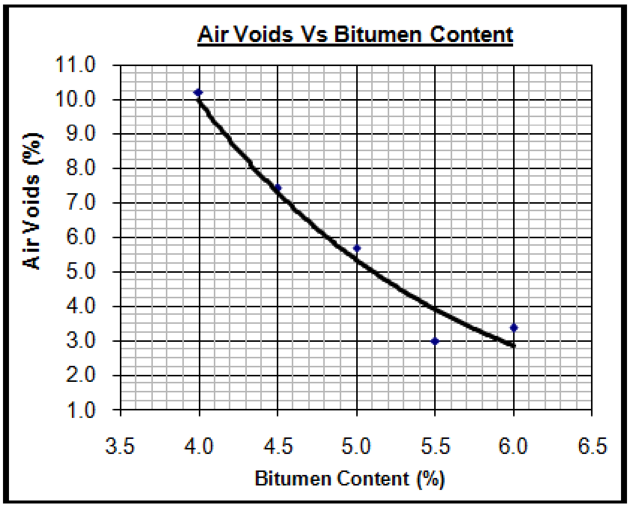

Figure 5. Air Void Vs. Bitumen Content

3.4.5. Flow

Flow represents the total amount of deformation, which occurred at the maximum load. From Figure 6 below, it can be seen that the highest flow of the asphalt mix was at 6% bitumen content. High flow values generally indicate a plastic blend that will experience permanent deformation under traffic, whereas low flow values may show a mix with higher than regular voids and insufficient asphalt for durability and may experience premature cracking due to mixture brittleness during the life of the pavement. From the graph, the flow was 3.7mm, at 5.1% bitumen content.

The flow value has a general trend of consistent increase with increasing asphalt content. For Marshall mix design, 75- blow compaction used, based on the high traffic volume, and the corresponding flow value, usually specified to be in the range of 2mm to 4mm.

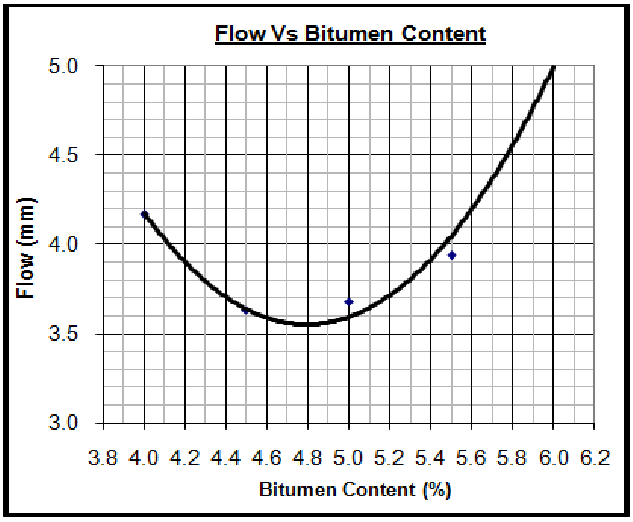

Figure 6. Flow Vs. Bitumen Content

3.4.6. Optimum Asphalt Content Determination

It is expected that the effective asphalt content determines the performance of the mixtures. It expressed as the effective asphalt content, which makes the asphalt film around the aggregate particles. If the asphalt film thickness around the aggregate particles is thick enough, various desirable characteristics such as better durability, more fatigue resistance, and higher resistance to moisture induced damage can be achieved from bituminous mixtures. But, there should be a maximum limit of the increase in temperature and loading, the asphalt content in the mix gets increased and resulting bleeding on the surface of paved road.

Table 7. Mechanical Properties of Asphalt Mix with SCD filler ingredient at 5.1% Bitumen Content

SCD Filler Content (%)	Sample No	Corrected Stability (KN)	Flow (mm)	Density (g/cm^3)	Air Void, Va (%)	VMA (%)	VFB (%)
0%		10.2	2.8	2.317	7.8	17.1	54.3
2%	1	11	3.02	2.364	5.7	15.4	6.2
	2	10	3.5	2.338	6.7	16.3	59
	3	11	3.2	2.334	6.9	16.5	58.4
Average		10.7	3.24	2.345	6.4	16.1	60.2
4%	1	10.4	2.97	2.382	5.6	14.8	62.5
	2	10.7	3.13	2.374	5.9	15.1	61.5
	3	11.5	3.4	2.387	5.4	14.6	63.4
Average		10.9	3.17	2.381	5.6	14.8	62.3
6%	1	13.1	3.6	2.378	5.1	15	65.9
	2	15.1	4	2.394	4.5	14.4	69
	3	13.4	3.4	2.405	4	14	71.2
Average		13.9	3.66	2.392	4.5	14.5	68.7
8%	1	11	3.02	2.443	3.7	12.6	70.4
	2	10	3.5	2.44	3.9	12.8	69.7
	3	11	4.3	2.446	3.6	12.5	71.1
Average		10.7	3.61	2.443	3.7	12.6	70.4

In the next section, Figure 7 was plotted to show the proper determination of the effective asphalt content for blended with Sub-base Course dust filler ingredient. It can be stated that as the effective asphalt content decreases, the filler content increases in the combination. This was because more voids are filled with mineral fillers as the filler content in the mix increases resulting in lower total asphalt content and hence, lowering the effective asphalt content. Besides, as the filler content increases, more asphalt is absorbed by fine aggregates due to the higher proportion of fines in the mixture.

Table 7 above shows the asphalt mixtures taken laboratory test results with different filler contents and the corresponding values of Marshall properties at 5.1% bitumen content. From these results, the Optimum SCD filler ingredient of 6% satisfied all parameters of the Marshall mix design.

Table 8. Summary of Marshall Test Result of the Study

Marshall Mix	Stability	Flow	VFB	VMA	VA	Density	OBC
Property	(KN)	(mm)	(%)	(%)	(%)	(g/cm^3)	(%)
Mix Criteria As per ERA Spec.	8 (Min.)	2-4	65 - 75	10 - 16	3 - 6	-	4 - 10
HMA without Filler	10.2	3.7	70.5	16.5	5	2.317	5.1
HMA with 6% SCD Filler	13.9	3.66	68.7	14.5	4.5	2.392	5.1

The above Table 8 shows the summary of the HMA results with and without filler material corresponding to the standard specification criteria.

Table 92. Marshall Test Results for Types of Fillers to OBC at different Fillers Content

Filler Type	% Filler	OBC (%)	Air Void (%)	VMA (%)	VFB (%)	Corrected Stability (KN)	Flow (mm)
HL	2	5.1	6.4	15.9	58.7	10.8	3.01
OPC	2	5.1	5.9	15.8	62.5	11.5	3.2
Marble Dust	4	5.1	4.8	16.5	70.5	10.2	3.7
Sub-Base Course Dust	0	5.1	7.8	17.1	54.3	10.2	2.8
	2	5.1	6.4	16.1	60.2	10.7	3.24
	4	5.1	5.6	14.8	62.3	10.9	3.17
	6	5.1	4.5	14.5	68.7	13.9	3.66
	8	5.1	3.7	12.6	70.4	10.7	3.61

Table 9 indicated the Marshall properties of the mixture corresponding to the filler content of the control mix as well as the mix modified with SCD filler. The optimum bitumen content of the control mix was 5.1%. The Marshall stability value of containing 2%, 4%, 6% & 8% of SCD filler provided a corresponding value of 10.7KN, 10.9KN, 13.9KN & 10.7KN, respectively. The flow values of all the mixes with optimum bitumen content lies in the specified range of 2mm to 4mm.

3.5. Relationship of Marshall Properties and SCD Filler Ingredient

3.5.1. Marshall Stability – SCD Filler Content Relationship

From Figure 7 below, it is noticed that all values of stability with different filler content have achieved the specification requirements. As shown below the stability of the mix with SCD increased as the filler content increases until it reaches the maximum stability that was 13.9KN at 6% SCD filler content, beyond that it started to decline.

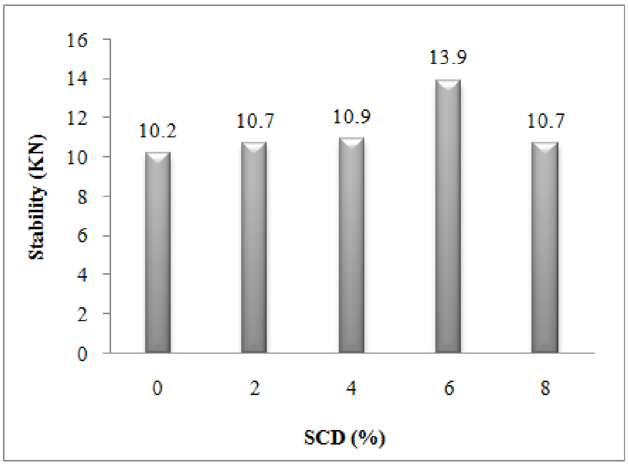

Figure 7. Asphalt Mix Stability – SCD Filler Content Relationship

3.5.2. Flow – SCD Filler Content Relationship

The flow of mixes with 6% SCD filler indicated a value of 3.66mm, and it was within the range of the specifications. Figure 8 shows flow value results of HMA in varying filler contents.

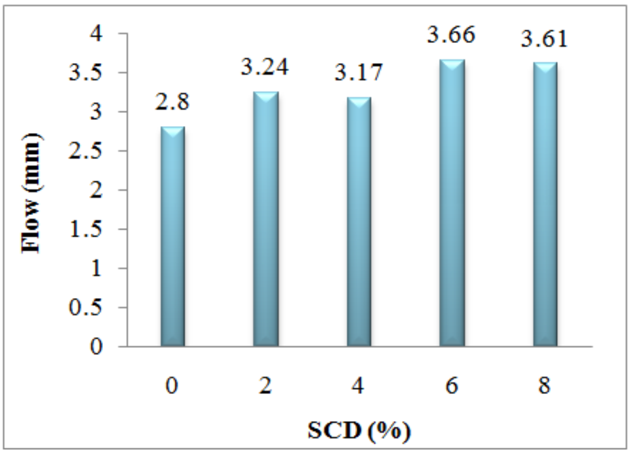

Figure 8. Asphalt Mix Flow – Filler Content Relationship

3.5.3. Bulk Density – SCD Filler Content Relationship

The bulk density of HMA with different percentages of SCD filler content achieved the specification requirements. The value of bulk density of 6% SCD filler ingredient was 2.392g/cm^3. The general trend indicated that the bulk density increases as the filler content increases. Figure 9 shows the asphalt mix bulk density at varying filler contents.

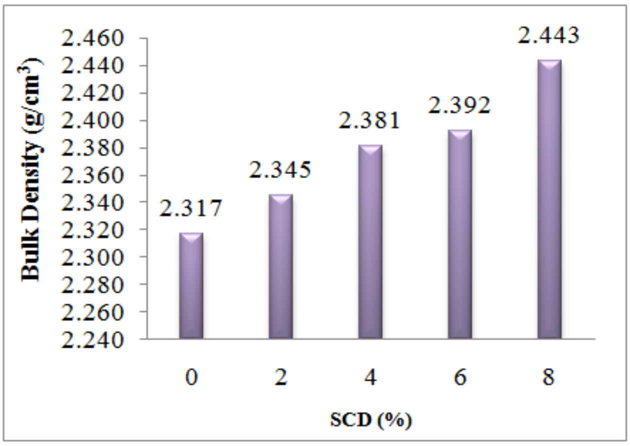

Figure 9. Asphalt Mix Bulk Density – Filler Content Relationship

3.5.4. Air Voids (VA) – SCD Filler Content Relationship

The air voids value of the mix decreased gradually as the SCD filler content increases. It indicated from the figure that at 6% filler content, the air voids percentage of 4.5%, represented the median value from the specification. Figure 10 shows the air voids values of asphalt mixes at varying filler content.

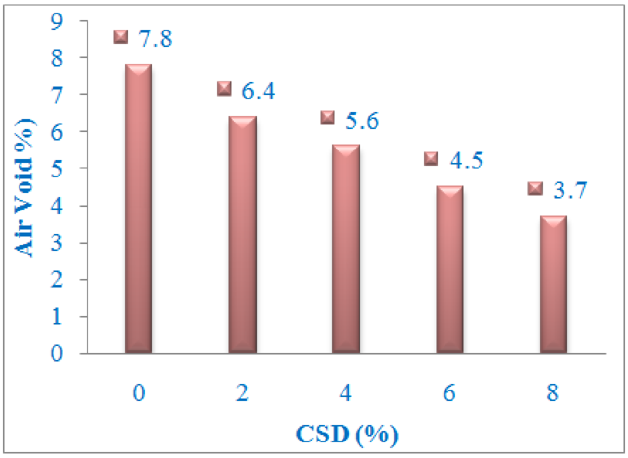

Figure 10. Asphalt Mix Air Voids – Filler Content Relationship

3.6. Summary of Laboratory Experiment of HMA Properties

Table 10 indicated the summary of HMA properties at varying SCD filler contents.

Table 10. Properties of Mixtures at varying SCD Filler Content

Property	SCD Filler Content (%)				
	0	2	4	**6**	8
Stability (KN)	10.2	10.7	10.9	**13.9**	10.7
Flow (mm)	2.8	3.24	3.17	**3.66**	3.61
Bulk Density (gm/cm^3)	2.317	2.345	2.381	**2.39**	2.443
% of Voids in Total Mix (VA)	7.8	6.4	5.6	**4.5**	3.7
% of Voids in Mineral Agg. (VMA %)	17.1	16.1	14.8	**14.5**	12.6
% of Voids Filled with Binder (VFB %)	54.3	60.2	62.3	**68.7**	70.4

3.7. Optimum SCD Filler Content

From Figure 7, all values of Marshall stability of varying SCD filler content satisfied the specifications from 8KN minimum. Results indicated the highest stability value of 13.9 kN at 6% SCD filler content. Likewise, Figure 10 represents the air voids percentage of different SCD filler content, and at 6% filler content the corresponding air voids value was 4.5% which is very close to the median air voids in the specifications. While, from Figure 9 it could be noticed that all values of bulk densities at varying SCD filler contents, are very close to each other and all of these values are consistent with the requirements of the specifications.

4. Conclusion

From the findings of the study, the researchers concluded that:

The properties of sub-base course dust (SCD) as a filler ingredient revealed its potential usage for hot mix asphalt. The investigation of SCD filler resulted in sound material's effect on the Marshall properties of the asphalt mixture.

The comparison of SCD with the conventional fillers and the standard specifications satisfied all the requirements to be used in HMA concrete.

Moreover, the outcome of Marshall parameters like stability, air voids, and bulk density values are consistent with the standard specifications at 6% SCD filler content. Therefore, SCD filler has a potential ingredient to be used in HMA concrete with an optimum content of 6%. It must be emphasized that considering such type of filler increases within the project locality, the standard procedures and specifications should have to be adhered.

References

[1] Brown E. Ray and Mallick Rajib B., "Stone matrix asphalt-properties related to mixture design. NCAT Report 94-2, National Center for Asphalt Technology, Auburn, Alabama, USA.," 1994.

[2] Yonas Ketema, Prof. Emer T. Quezon, Getachew Kebede, "Cost and Benefit Analysis of Rigid and Flexible Pavement: A Case Study at Chancho –Derba-Becho Road Project," IJSER, vol. 7, no. 10, p. 181-188, 2016.

[3] ERA Manual, "Standard Technical Specification" 2002.

[4] Ilan Ishai Joseph Craus and Arieh Sides, "A Model for Relating Filler Properties to Optimal Behavior of Bituminous Mixtures," AAPt', vol. 49, 1980.

[5] Kandhal P.S. et al., "Characterization tests for mineral fillers related to the performance of asphalt paving mixtures," NCAT Rep., vol. 98, no. 2, 1998.

[6] Asi Ibrahim and Assa'ad Abdullah, " Effect of Jordanian oil shale fly ash on asphalt mixes," J Mater CivEng, vol. 17, p. 553–9, 2005.

[7] Anderson D.A. et al., "Rheological properties of mineral filler asphalt mastics and their relationship to pavement performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society for Testing Materials, Philadelphia, USA," 1992.

[8] Anderson, D. A., "Guidelines for the use of dust in hot mix asphalt concrete mixtures."Proc. Association of Asphalt Paving Technologists, 56, Association of Asphalt Paving Technologists, St. Paul, MN, 492-516, 1987.," St. Paul. MN., p. 492-516, 1987.

[9] Bahia H.U.et al, "Non-linear visco-elastic and fatigue properties of asphalt binders," Journal of Association of Asphalt Paving Technology, vol. 68, pp. 1-34, 1999.

[10] Transportation American Association of State Highway, "AASHTO M-17 Standard specification for mineral filler for bituminous paving mixtures", Washington DC, 20001, 2008.

[11] Bahia H. U. et al., "Test methods and specification criteria for mineral filler used in HMA."NCHRP Research Results Digest, 357, Transportation Research Board, Washington, DC.," 2011.

[12] Kadeyali, Principles, and practice of Highway Engineering, 3rd ed., 1997.

[13] ASTM D6927-10. Standard Practice for Marshall Stability and Flow of Asphalt Mixture, Annual book of ASTM standards, West Conshohocken, 2010.

[14] Zulkati A. et al., "Effects of Fillers on properties of Asphalt-Concrete Mixture," Journal of Transportation Engineering, ASCE, vol. 138, no. 7, pp. 902-910, 2012.

[15] Sung Do Hwang et al., "A study on engineering characteristics of asphalt concrete using filler with recycled waste lime," Waste Manage, vol. 28, p. 191–199, 2008.

[16] Geber R. and Gomze L.A., "Characterization of mineral materials as asphalt fillers," Material Science Forum, vol. 659, pp. 471-476, 2010.

[17] Taylor R., "Surface interactions between bitumen and mineral fillers and their effects on the rheology of bitumen-filler mastics. Ph.D. thesis, Univ. of Nottingham, UK," 2007.

[18] Kandhal P.S. et al., "Characterization tests for mineral fillers related to the performance of asphalt paving mixtures," NCAT Rep., vol. 98, no. 2, 1998.