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Evaluation on the Potential Use of Pulverized Natural Subbase Dust as Alternative Filler Material for Hot Mix Asphalt Design, Jimma Town

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Abstract A well-designed asphalt mixture is expected to serve effectively for many years under a variety of loading and environmental conditions. Bituminous concrete is one of the highest and costliest types of flexible pavement. One of the main problems in the construction of asphalt paving mixture is obtaining a sufficient amount of filler material and high cost of the use of ordinary Portland cement, hydrated lime, or marble dust as filler material. Asphalt Institution restricted the use of a maximum limit of 2% proportion to improve the aggregates adhesion properties only, which is not sufficient quantity to achieve the grading requirements. To alleviate this problem, it is important to come across alternative filler material that can be used in more quantity. The study has investigated the potential use of natural subbase dust (MSD)as alternative filler material, and their characteristic on the effect of hot asphalt mixture was identified. This research was conducted by using Experimental Research Design. In total, 48 samples were prepared according to ASTM D1559, of which 15 of them used to calculate the OBC and the rest to find out the effects of adding different percentages of NSD to the asphalt mixture. For this purpose, five different bitumen contents were used (4%–6% with 0.5% increments). Aggregate mixtures blended without filler and with NSD filler were investigated to evaluate their Marshall properties on HMA mixtures. Four varying percentages of NSD ranging from (2% - 8% at 2% increments) were used for Marshall experiments. And for the control mix, 2% hydrated lime (HL) and 2% ordinary Portland cement used in the mixture besides, 4% Marble Dust was used as a reference. The aggregates were blended by using Job mix formula to obtain the percentage of material proportion. As a result for aggregates blended without filler G-1 (26%), G-2 (23%) and G-3 (51%) proportion were used whereas for aggregates blended with NSD filler, G-1 (26%), G-2 (22%), G-3 (46%) and G-4 (6%) was utilized. Where G-1 is Coarse Aggregate 3/4, G-2 is Intermediate Aggregate 3/8, G-3 is Fine Aggregate, and G-4 is NSD filler. Based on Marshall test results, the OBC was found 5.1% by the total asphalt mix. Furthermore, examining Marshall mixes containing different percentages of filler showed the optimum percentage of NSD was 6%. The Marshall properties of the experiments at 6% NDS filler resulted in high stability, low flow, lower VFB, low VMA & lower air voids that are consistent with the standard specifications. The investigation of NSD filler has resulted in good effects on the Marshall properties of the asphalt mixture. Furthermore, the outcome of Marshall parameters like stability, air voids, and bulk density values was consistent with the standard specifications. Therefore, NSD filler can potentially be used as an alternative filler material in HMA with optimum filler content of 6%. Besides, it is recommended to exercise the use of NSD as filler material in HMA projects in order to ensure the quality of works, save transportation costs and save time spend to import other filler materials from far away. It is also recommended combining NSD filler with other materials may produce a better outcome on the effects on the asphalt mix properties.

Keywords: *Aggregates, Natural Subbase Dust Filler, Bituminous Paving Mixes, Cement Hydrated Lime, Marble Dust, Marshall Mix Design, Optimum Filler Content*

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1. Introduction

The construction and maintenance of highway pavement in Ethiopia requires a large number of good quality materials. The fast growth of continual heavy axel traffic demands a better quality of material for paving applications. The development and use of modified asphalt mix can meet the needs of the communities. Asphalt modification can be realized primarily through polymer modification. However, this method is expensive due to the high cost of raw polymer, skilled personnel, and special equipment. In the other method, asphalt mix modification can be done by replacing common fillers like lime, cement, and other suitable materials [1].

Highway pavements are categorized into two groups rigid and flexible. Rigid pavements are composed of a cement concrete surface course, and flexible pavements are those surfaced with bituminous materials. Asphalt concrete is a mixture of aggregate, bitumen, and filler in a different relative amount that sets up the substantial property of mix. Pavement systems in Ethiopia are exposed to a multitude of severe environmental factors, mainly heavy axle load applied on the road, high traffic, and excessive-high temperature [2]. The road usually exhibits excessive failures at an early stage of the pavement life. A major step in the improvement of the existing performance of roads starts with the modification of mix design. The strength, cost, and stability of asphalt mixtures are influenced by several features together with a gradation of aggregates, types, and amounts of filler materials. Ilan Ishai et al. investigated the major role of fillers as they play a crucial role in the properties and behavior of bituminous paving mixtures. The mechanical properties of bituminous road pavement depend decisively upon the properties of filler and bitumen. Modifications of asphalt paving materials that have high-quality additives are quite expensive for the mass production of bituminous mixtures. A solution to solve this problem is by considering the influence of natural mixture ingredients, such as filler [3].

Kandhal et al. conducted various studies that the properties of mineral fillers, especially the material passing 0.075mm (No. 200) sieve, have a significant effect on the performance of asphalt paving mixture in terms of deformation, fatigue cracking and moisture susceptibility. Mineral fillers were originally added to dense-graded HMA paving mixtures to fill the voids in the aggregate skeleton and to reduce the voids in the mixture [4]. Asi Ibrahim and Assa'ad Abdullah studied fillers that are used in the asphalt mixture to affect the mix design, especially the optimum asphalt content. The term filler is often used loosely to designate a material with a particle size distribution smaller than No. 200 sieve. The filler 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 large area of contact between particles. It was found that fillers increase the required compactive effects of specimens to the same volume of air void content. The function of mineral filler is essentially to stiffen the binder [5].

Various conventional materials such as cement, lime, granite powder are normally used as filler in asphalt concrete mixture in another world. Cement, lime, and granite powder are expensive and are used for other purposes more effectively. From the economic point of view, the researcher has investigated and evaluated the potential use of natural subbase dust as alternative filler material in hot asphalt concrete mixture and compared with the conventional fillers and with standard specifications [6]. The study also evaluated the effects of natural subbase dust filler on the Marshall properties. Based on the experimental results, the feasibility of natural subbase dust as an alternative filler with optimum proportion was assessed by comparing with the control mixtures and standard specifications.

Fillers have traditionally been used in asphalt mixtures to fill the voids between the larger aggregate particles [7]. Bahia et al. investigated the influence of different types of fillers on the properties of asphalt concrete mixture as it varies with the particle size, shape, surface area, surface texture, and other physical-chemical properties [8]. Conventionally in Ethiopia, fine sand, cement, hydrated lime, crushed stone, and marble dust are used as filler material in the bituminous mix. One of the main problems in the construction of asphalt paving mixture is obtaining a sufficient amount of filler material and high cost of the use of cement or marble dust as filler material. Since OPC and HL are restricted by Asphalt Institution, the use of a maximum limit of 2% proportion to improve the adhesion property of the aggregates only, which is not sufficient quantity to achieve the grading requirements. On the other hand, marble dust is obtained from a waste product of marble industries far away and with a long period waiting for obtaining sufficient quantity. If this dust is not deposited with care by avoiding moisture absorption, it requires a long period to get dry.

In this study, an attempt was made to find effective types of cheap and non-conventional filler on the behavior of bituminous mixes. For this purpose, natural subbase dust was used as a non-conventional filler. The characteristics of the mixtures containing different types of filler were evaluated by examining fundamental material properties and by performing various laboratory tests. Then the results obtained for mixed type containing non-conventional fillers were compared with the conventional fillers.

2. Study Area, Materials and Research Methodology

2.1. Project Location and Topography

The study area that was considered is the Jimma zone, where all materials are collected for the experiment. It is located at southwestern of Ethiopia at 355kms away from Addis Ababa. Its geographical coordinates are between 7° 13'- 8° 56N latitude and 35°49'-38°38'E longitude with an estimated area of 19,506.24. Jimma town is found in an area of average altitude of about 1780m above mean sea level. It lies in the climatic zone, locally known as Woyna-Dega.

Figure 1. Map of the study area. (Source:Google Map 2017)

2.2. Research Design

This research employed a laboratory experimental research design. After organizing a literature review of different previously published investigations, the study evaluated the performance of the natural subbase dust as filler for asphalt mix design. In particular, the researcher performed all materials such as asphalt binder, coarse aggregate, fine aggregate, and fillers, under AASHTO (T49, T 53, T 228, and T 179, while for binder based on ASTM D854 laboratory procedures. For the accomplishment of this research goal, the applicable practice work, research findings, and other information on the filler material for the asphalt pavement mixture reviewed.

In this study, the Marshall mix design method used to design the HMA mixes. The standard Marshall specimens prepared by applying 75 blows on each face, according to ASTM: D6926 (ASTM D 6926, 2010) having five different bitumen content between 4% and 6% by total weight of aggregate at 0.5% increment. For the control mixes, 2% hydrated lime and 2% ordinary Portland cement used. Besides, 4% of Marble dust filler, which is the mix design considered at the Jimma town hot mix asphalt project, and used as a reference. Further, mixed containing 2%, 4%, 6%, and 8% natural subbase dust filler used for evaluating its respective performance.

The data processing and analysis consisted of four stages:

1. Characterizing the materials;
    - Asphalt binder, Aggregates, Fillers
2. Design the mixtures with NSD filler;
    - Marshal Mix Design for the fillers
3. Evaluation of NSD;
    - Suitability Evaluation in HMA concrete mixtures
4. Data analysis
    - Results analyzed with Microsoft Office Excel Program.

2.3. Materials

The Penetration grade 85/100 of asphalt cement used in this study obtained from the ERCC laboratory, while the coarse, intermediate, and fine aggregates collected from the ERCC crusher site located at Unkulu woreda, Jimma Zone, and it was part of the ingredients for the laboratory experiment. Screened natural subbase was obtained from the Red Cross Quarry site 7.0kms away towards Jimma - Addis road.

2.4. Tests and Materials Preparation

2.4.1. Mineral Aggregate

Based on the Ethiopian Road Authority (ERA) Standard Specifications, aggregates component accounted for 92% to 96% of hot mix asphalt (HMA) by weight. The aggregates locally available were having a specific gravity of 2.72 and 2.59 for coarse and fine aggregate used, respectively. ERA and AASHTO specifications applied in this study for continuous aggregate gradation for the used in the hot mix asphalt experiment.

2.4.2. Physical Properties of Aggregates

2.4.2.1. Sieve Analysis

The gradation of a combination of aggregates is one of the critical aspects when studying the behavior of asphalt mixes. Laboratory experiment based on the universal specification ASTM D3515 and a gradation test according to specification (ASTM C136). It is performed on samples for each type of aggregates in the laboratory, and the results are presented in Table 1. The Job-Mix-Formula for the aggregate particle size distribution used for the preparation of mixtures before and after blending.

Table 1. Composition of Asphalt Paving Mixture Specification ASTM D3515

Mix Designation and Nominal Maximum Size of Aggregate [10]								
Sieve Size		2in (50mm)	1 1/2in (37.5mm)	1in (25.0 mm)	3/4 in (12.5mm)	1/2 in (12.5mm)	3/8in (9.5 mm)	No. 4 (4.75 mm)
2 1/2"	63 mm	100	......	......	......	......	......	......
2"	50 mm	90 -- 100	100	......	......	......	......	......
1 1/2"	37.5 mm	......	90 --100	100	......	......	......	......
1"	26.5 mm	60 -- 80	......	90 -- 100	100	......	......	......
3/4"	19 mm	......	56 -- 80	......	90 --100	100	......	......
1/2"	12.5 mm	35 -- 65	......	56 -- 80	......	90 --100	100	......
3/8'	9.5 mm	......	......	......	56 --80	......	90 --100	100
No. 4	4.75 mm	17 -- 47	23 -- 53	29 -- 59	35 -- 65	44 --74	55 -- 85	80 -- 100
No.8	2.36 mm	10 -- 36	15 -- 41	19 -- 45	23 -- 49	28 --58	32 -- 67	65 -- 100
No. 16	1.18 mm	......	......	......	......	......	......	40 -- 80
No. 30	0.6 um	......	......	......	......	......	......	25 -- 65
No. 50	0.3 um	3 -- 15	4 -- 16	5 -- 17	5 -- 19	5 -- 21	7 -- 23	7 -- 40
100	0.15 um	......	......	......	......	......	......	3 -- 20
0.075	0.075 um	0 -- 5	0 -- 6	1 -- 7	2 -- 8	2 -- 10	2 -- 10	2 -- 10
Bitumen, Weight % of Total Mixture								
Range		2--7	3--8	3--9	4 -- 10	4 -- 11	5 -- 12	6 -- 12

Source: Asphalt institution of Hot Mix Asphalt Pavement Manual, Series No.22, 2nd edition

2.4.2.2. Los Angeles Abrasion

The Los Angeles Abrasion (LAA) test is a standard test method used to show aggregate toughness and abrasion characteristics. The aggregate's abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation, and disintegration to produce a high-quality hot mix asphalt.

Figure 2. Equipment Used for the L.A. Abrasion Test

The LAA test measures the degradation of a coarse aggregate sample that is placed in a rotating drum with steel spheres, as shown in Figure 2. As the drum rotates, the aggregate degrades by abrasion and impact with other aggregate particles and the steel spheres (called the "charge"). Once the test completed, the mass of aggregate calculated that had crushed a part to smaller sizes expressed as a percentage to the total weight of aggregate. Therefore, lower L.A. abrasion loss value indicated aggregate is tougher and more resistant to abrasion.

2.4.2.3. Aggregate Crushing Value (ACV)

Aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under a gradually applied wheel load as a compressive load [9]. The standard aggregate crushing test was done on aggregates passing on sieve no. 12.5mm and retained on sieve no. 9.5mm based on the AASHTO test, as shown in Table 2.

Table 2. Aggregate Crushing Value Lab Result

Aggregate Crushing Value Test BS 812 Part 110:1990		
Sample No.	1	2
Size of aggregates, mm	10 - 14	10 - 14
Maximum load applied, kN	400	400
Duration of testing, mm	10	10
Weight of sample tested, gm	2656.3	2633.8
Wt. of sample ret. on 2.36 sieve, gm	2201.2	2204.1
Aggregate Crushing Value (%)	17.1	16.3
Average aggregate. crushing value (%)	16.7	

2.4.2.4. Aggregate Impact Value

The standard aggregate impact test performed on aggregates passing on sieve no. 12.5mm and retained on sieve no. 10 .0mm per AASHTO test. If an aggregate impact value is higher than 30, it has a questionable result. Also, aggregate sizes larger than 12mm are not appropriate for the aggregate impact test.

2.4.2.5. Particle Shape and Surface Texture

Rounded particles create less particle-to-particle interlock than angular particles and thus providing better workability and easier for compaction. However, in HMA, less interlock is generally a disadvantage as a rounded aggregate will continue to compact, shove, and rut after construction. Thus, the angular particles are desirable for HMA despite their poor workability. These particles tend to impede compaction or break during compaction and, therefore, may decrease strength.

Hot mix asphalt tends to bond more effectively with rough-surfaced particles. Thus, rough-surface particles are desirable for HMA. The flat and elongated particle test used to determine the dimensional ratios for aggregate particles of specific sieve sizes.

2.4.2.6. Asphalt Binder Selection

High-performance applications require small amounts of polymers are sometimes blended into the asphalt binder, producing a polymer-modified binder. In general asphalts, can be classified into three general types:

- Asphalt cement
- Asphalt emulsion
- Cutback asphalt

Cutbacks and emulsions are used almost entirely for cold mixing and spraying and will not apply for hot mix asphalt mixture [9]. Because of its chemical complexities, asphalt specifications have been developed around physical property tests, such as penetration, viscosity, and ductility. These tests performed at standard test temperatures, and the results used to determine if the material meets the specification criteria.

Asphalt binders are advantageous and valuable material for constructing flexible pavement worldwide. However, they have very unusual engineering properties that must be carefully controlled to ensure proper performance. Asphalt pavement at high temperature will become soft that will be prone to shoving and rutting. While an asphalt pavement at low temperatures is too hard and inclined to low-temperature cracking. There is an extreme change in modulus that occurs in asphalt binders over the range of temperatures. Specifications for bitumen binders must control the properties at low, high, and intermediate temperatures when applied in the project site. Furthermore, test methods used to specify bitumen binders usually must be performed with very careful temperature control. Otherwise, the output is not satisfactory.

2.4.2.7. Asphalt Binder Test

For this experimental research works, bitumen of Penetration grade 85/100 used and collected from ERCC Ethiopian Road Construction Corporation laboratory. The main reason for using this grade was because of its common type and widely used in most road projects in the project area, and also based on the temperature and traffic condition.

a) Penetration

The penetration test is an empirical measure of the hardness of asphalt at room temperature. The standard penetration test started with conditioning a sample of asphalt cement to a temperature of 25°C submerged in a water bath.

b) Flashpoint

The flashpoint of asphalt cement is the lowest temperature at which volatile gases separate from a sample to “flash” in the presence of an open flame. The asphalt flashpoint is determined to identify the maximum temperature at which it can be handled and stored without danger of flashing.

c) Specific Gravity

Specific gravity is the ratio of the weight of any volume of a material to the weight of an equal volume of water both at a specified temperature [9]. There are two reasons needed to know about the specific gravity of asphalt cement. On the other hand, asphalt expands when heated and contracts when cooled. It means the volume of a given amount of asphalt cement is greater at higher temperatures than at lower ones. On the other hand, the specific gravity of asphalt is essential in the determination of the effective asphalt content and the percentage of air voids in compacted mix specimens and compacted pavement.

d) Ductility

Sample of asphalt cement can stretch before it breaks into two parts; we can call it ductility. It is used in the penetration and viscosity classification systems and measured by an "extension" test in which a briquette of asphalt cement is extended or stretched, at a specific rate and temperature [9].

e) Solubility

The solubility test measures the purity of asphalt cement. A sample was immersed in a solvent to dissolve the asphalt. Impurities such as salt, free carbon, and non-organic contaminants do not dissolve. These insoluble impurities are filtered out of the solution and measured as a proportion of the original sample [9].

f) Softening Point

The softening point test may be classed as a consistency test that measures the temperature at which the bituminous materials reach a given consistency as determined by the test conditions. It is applicable to semi-solid materials and is useful in characterizing bitumen.

2.4.3. Mineral Fillers

The fillers used for the study were screened and pulverized natural subbase material. The natural subbase samples collected from the selected quarry site according to ERA and AASHTO standards. The sample selections were dependent on the types of tests required as per standards, and for each analysis, quartering and weighting sampling technique used.

The sample natural subbase material screened, pulverized, and sieved to obtain the dust part that passes on number 200 sieve. Then the corresponding Marshall laboratory tests conducted after blending the dust filler with the aggregates at different mix proportions. Besides, for all materials such as asphalt binder, aggregate and filler material laboratory tests were carried out to determine the physical properties affecting the bituminous mixture property such as gradation parameters and plasticity index. The works carried out are shown in Figure 3 below.

Figure 3. Preparation for Lab Test of Physical Property of Natural Subbase Material (Source: Photos taken during the laboratory works)

2.5. Asphalt Mix Design

The hot mix asphalt produced by blending the asphalt and aggregate in precise proportions. The relative proportions of the materials determine the physical properties of the materials in the finished pavement. There are three commonly used design procedures for determining a suitable proportion of asphalt and aggregate in a mixture such as the Marshall Method, Hveem Method, and the Superpave Method.

2.5.1. Marshall Mix Design

The Marshall method was used in this study to design the paving mixtures developed by Bruce Marshall, who is Bituminous Engineer at Mississippi State Highway Department. The Marshall method applies only to hot mix asphalt using penetration, viscosity, asphalt binder or cement and containing aggregate with a maximum size of 25mm or less.

The purpose of the Marshal method is to determine the optimum asphalt content for a particular blend of aggregate. And also, it provides information about the properties of the resulting pavement mix, including density and void content, which employed during pavement construction.

The Marshall method uses standard test specimen 64mm high and 102mm internal diameter. A series of samples, each containing the same aggregate blended but varying in asphalt content from 4% to 6% with an increment of 0.5% prepared using a specific procedure to heat, mix and compact the asphalt aggregate mixtures.

2.5.2. Experimental Work

After evaluating the properties of used materials that are bitumen, aggregates, and natural subbase dust, sieve analysis was performed. Then for each type of aggregates blending carried out to obtain the binder course gradation curve, which utilized in the preparation of the asphalt mixture.

After that, with different bitumen contents, asphalt mixes were prepared to obtain optimum bitumen content by the Marshall test. Then the optimum bitumen content was used to make asphalt mixes with various percentages of natural subbase dust filler. Finally, the Marshall test used to evaluate the properties of these natural subbase dust fillers in the mixtures and the corresponding laboratory test results obtained, tabulated. It analyzed with Microsoft Office Excel 2007 Program.

2.5.3. Preparation of Mixtures

In determining the design asphalt content for a particular blend or gradation of aggregate by the Marshall method, a series of test specimens prepared for a range of different asphalt contents. According to ASTM specifications using mathematical trial method aggregates blended together to get a proper gradation. The precise trial method depends on suggesting different trial proportions for each type of aggregate. The percentage of each type of aggregate was computed and compared with the specification limits.

Figure 4. Preparation of Aggregate for Specimen of Marshall Test (Source: Photos taken during the laboratory works)

Figure 4 shows the preparation of aggregates for Marshall tests.

2.5.4. Marshall Test Method

The Marshall Stability test was used in this study for both determining the optimum binder content (OBC) and evaluating the specimens of natural subbase dust filler. This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface through the Marshall apparatus, according to ASTM D1559-89 [10]. The prepared mix placed in a preheated mold (101.6mm) in diameter by (63.5mm) in height and each face of the specimen compacted with 75 blows.

The samples were then left to lower the temperature at room temperature within 24 hours. The Marshall stability and flow tests performed for each sample. The cylindrical sample was placed in a water path at 60ºC for 30 to 40 minutes then compressed on the lateral surface at a constant rate of 50.8mm/minute until the maximum load (failure) reached. The maximum load resistance value and the flow values were recorded. There were three samples for each material combination set up, and the average value from the results recorded. The Density, bulk specific gravity, density, air voids in total mix, and voids filled with bitumen percentages are determined for each sample.

2.5.5. Optimum Binder Content

Marshall Test was used to determine the optimum binder content. Five percentages of bitumen examined to determine the best percentage of bitumen for the aggregates used with 4, 4.5, 5, 5.5, and 6% by weight of the mix with three samples for each. The optimum binder content was found equal to 5.1% by weight of the total mix, computed based on the mean value of binder content that corresponds to the maximum stability, maximum density, and median percent of air voids.

2.5.6. Optimum Natural Subbase Dust Content

Several laboratory investigations performed to determine the mixed properties of natural subbase dust filler using the Marshall test procedure. All mixtures prepared with the same binder content o of 5.1%. The best percentage of natural subbase dust that can be used as filler in the mixture determined by investigating four percentages of screened and pulverized natural subbase dust filler which composed of 2, 4, 6, and 8% by weight of the total aggregate with three samples for each percentage.

The steps applied in preparing natural subbase dust filler samples are summarized as follows:

a) Natural subbase material was screened, pulverized, and then sieved.

b) The gradation of used Natural subbase dust (NSD) filler checked for uniformity with the grain size distribution of other conventional fillers.

c) Four percentages of 2% - 8% by weight of the total aggregate of NSD with a 2% incremental investigated with three samples for each portion.

d) NSD filler was mixed with other aggregates using the percentages mentioned above and then heated to a 135°C temperature before blending with the bitumen.

e) Before blending with aggregates, asphalt was heated up to 145°C. Pre-heated asphalt was avoided, and excess heated asphalt was disposed of to prevent variability in the asphalt properties.

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

g) Standard Marshall molds heated in an oven up to 130ºC, and then the hot mix placed in the mold and each face of the specimen was compacted with 75 blows.

h) Samples were prepared, compacted, and tested according to the Marshall method designated in ASTM D1559-89.

2.5.7. Mixture Characteristics and Behavior

Samples for paving mixture were prepared in the laboratory to analyze and to determine their probable performance in a pavement structure. The analysis focused on four characteristics of the mixture and their influence on the behavior of the mixture. These are Mix Density, Air Void, Void in the mineral aggregate, and Asphalt content.

a) Mix Density

The mixed density of the compacted asphalt is the unit weight or the mass of a given volume of the mix ingredients. Density is particularly important because a high density of the finished pavement is essential for lasting pavement performance. In mixed design testing and analysis, the density of the compacted specimen is usually expressed in kilograms per cubic meter (kg/m^3). It was calculated by multiplying the bulk specific gravity of the mix with a density of water [(1,000 kg/m^3 or 62.43 lbs. /ft^3].

The bulk specific gravity of a mixture refers to the specific gravity of a specimen of [9] a compacted mixture, including the volume of air voids within the mix. It is equal to the mass of a sample in grams, divided by its total amount in cubic centimeters. The bulk specific gravity of an asphalt concrete mixture can be determined using either laboratory compacted samples or cores cut from a pavement.

The standard procedure for computing the bulk specific gravity of compacted asphalt concrete involves weighing the sample in air and water. The following formula used for calculating bulk specific gravity of a saturated surface-dry sample:

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

Where;
G_{mb}= Bulk Specific gravity of a compacted sample
A = Sample dry mass air, g
B = Mass of the saturated surface-dry sample in air, g, and,
C = Sample mass in water, g

The specimen density and the maximum theoretical density are determined in the laboratory. Each is used as standards to determine whether the density of the finished pavement meets specification requirements or not.

b) Air Voids

The Air voids are small pockets of air between the coated aggregate particles in the final compacted Hot mix asphalt (HMA). Air void content does not include pockets of air within individual aggregate particles, or air contained in microscopic surface voids or capillaries on the surface of the aggregate [9]. Air voids value is necessary for the hot mix asphalt to allow for a slight amount of compaction under traffic, and a slight amount of asphalt expansion due to temperature increases. The allowable percentage of air voids in laboratory specimens is between 3 % and 5% for surface and base courses, depending on the specific design [10].

The density and durability of asphalt pavement is a function of the air void content. Therefore, designing and maintaining proper air void content in HMA and other mix types are important for several reasons. If air void contents are too high, the pavement may be too permeable to air and water, resulting in significant moisture damage and rapid hardening. When air void contents are too low, the asphalt binder content may be too high, exhibited in a mixture prone to rutting, bleeding, and shoving.

In determining the air void content is one of the main purposes of volumetric analysis. Unfortunately, there is no simple direct way to determine the air void content of an asphalt concrete specimen. Air void content determined by comparing the specific gravity (or density) of a compacted specimen with the maximum theoretical density of the mixture used to make that specimen [11]. Density and air void content are directly related. The higher the density is, the lower the void in the mix will be. Job specifications usually require the pavement compaction to achieve an air void content of less than 8% and more than 3%. Air void content is calculated from the mixture bulk and theoretical maximum specific gravity [12]:

$$Va = 100\left[1-\left[\frac{Gmb}{Gmm}\right]\right] \qquad (2)$$

Where;
V_a = Air void content, volume %
G_{mb} = Bulk specific gravity of the densified mix
G_{mm} = Maximum specific gravity of the loose mixture

c) Voids in Mineral Aggregate (VMA)

The Voids in Mineral Aggregate is the inter-granular void spaces that exist between the aggregate particles in a compacted paving mixture. VMA includes air voids and spaces filled with asphalt. VMA is a volumetric measurement expressed as a percentage of the total bulk volume of a compacted mix. VMA represents; the space that is available to accommodate the effective volume of asphalt and the volume of air voids necessary in the mixture. The more VMA in the dry aggregate, the more space is available for the films of asphalt [14]. The durability of the mix increases with the film thickness on the aggregate particles. Therefore, specific minimum requirements for VMA are recommended and specified as a function of the aggregate size.

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

Where; [12]
VMA =Voids in the mineral aggregate, % by total mixture volume
V_a = Air void content, % by total mixture volume
V_{be} = Effective binder content, % by total mixture volume

The minimum VMA is necessary to achieve an adequate asphalt film thickness, which results in durable asphalt pavement—increasing the density of the gradation of the aggregate to a point where below minimum VMA values are obtained leads to thin films of asphalt and a low durability mix [13]. To economize asphalt content is to lower the VMA is counter-productive and detrimental to pavement quality; hence, not advisable. Table 3 shows the nominal and minimum specification limits for VMA.

Table 3. Void in Mineral Aggregate (ERA Manual)

Nominal maximum particle size (mm)	7.5	28	20	14	10	5
Minimum void in mineral aggregate, (%)	12	12.5	14	15	16	18

d) Binder Content

Asphalt binder content can be calculated in four different ways: total binder content by weight, effective binder content by weight, total binder content by volume, and effective binder content by volume. Total asphalt content by volume is calculated as the percentage of the binder by total mix mass [9]:

$$Pb = 100\left[\frac{Mb}{Ms + Mb}\right] \qquad (4)$$

Where;

Pb = Total asphalt binder content, % by mix mass
Mb = Mass of binder in sample
Ms = Mass of aggregate in sample

It can be calculated the total asphalt binder amount by volume in terms of a percentage from the total mix volume using the equation below:

$$Vb = \left[Pb * \frac{Gmb}{Gb}\right] \qquad (5)$$

Where; [9]

V_b = Total asphalt binder content, % by total mix volume
P_b = Total asphalt binder content, % by mix mass
G_{mb} = Bulk specific gravity of the mixture
G_b =Specific gravity of the asphalt binder.

The absorbed asphalt binder content by volume is also calculated as a percentage of total mix volume.

$$Vba = Gmb\left[\left(\frac{Pb}{Gb}\right) + \left(\frac{Ps}{Gsb}\right) - \left(\frac{100}{Gmm}\right)\right] \qquad (6)$$

Where; [9]

V_{ba} = Absorbed asphalt content, % by total mixture volume
G_{mb}= Bulk specific gravity of the mixture
P_b= Total asphalt binder content, % by mix mass
G_b= Specific gravity of the asphalt binder
P_s = Total aggregate content, % by mix mass = 100 - P_b
G_{sb}= Average bulk specific gravity for the aggregate blend
G_{mm}= Maximum specific gravity of the mixture

The effective asphalt by volume is found by subtracting the absorbed asphalt content from the total asphalt content:

$$Vbe = (Vb - Vba) \qquad (7)$$

Where; [9]

V_{be}= Effective asphalt content, % by total mixture volume
V_b= Total asphalt binder content, % by mixture volume
V_{ba}, = Absorbed asphalt content, % by total mixture volume

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

$$Pba = Pb - Pbe \qquad (8)$$

$$Pbe = Pb\left[\frac{Vbe}{Vb}\right] \qquad (9)$$

Where;

P_{be} = Effective asphalt binder content, % by total mass
P_b = Asphalt binder content, % by total mass
V_{be} = Effective asphalt binder content, % by total mixture volume
V_b = Asphalt binder content, % by total mixture volume
P_{ba} = Absorbed asphalt binder, % by total mixture mass

e) Voids Filled with Asphalt

The acceptable range of Voids Filled with Asphalt (VFA) varies depending upon the traffic level for the facility. Higher traffic requires a lower VFA because mixture strength and stability is more of a concern. Smaller traffic facilities require a higher range of VFA to increase HMA durability. A VFA that is too high, however, will generally yield a plastic mix. VFA is the effective binder content expressed as a percentage of the VMA [9]:

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

Where;

VFA = voids filled with asphalt, as a volume %age
VMA =Voids in the mineral aggregate, % by total mixture volume
V_a = Air void content, % by total mixture volume

2.6. Test Procedure

In the Marshall Method of pavement mix design after preparation of a test sample, the next step, each compacted sample is subjected to the listed below tests and analysis:

1. Bulk Specific gravity determination.
2. Stability and flow test.
3. Density and Void analysis.

a) Marshall Testing Machine:

It is a compression testing device designed to apply loads to test specimens through cylindrical segment testing heads (inside radius of curvature of 51mm at a constant rate of vertical strain of 51mm per minute). Two perpendicular guideposts are included to allow the two segments to maintain horizontal positioning and free vertical movement during the test. It is equipped with a calibrated proving ring for determining the applied testing load; a Marshall Stability apparatus is used in testing the asphalt concrete sample. Figure 5 below shows experimenting on the Marshall test Machine.

Figure 5. Marshall Stability Test (Source: Photo taken during the experiment)

Figure 6. Samples in Water Bath. (Source: Photo was taken during the experiment)

b) Water Bath

A water bath is at least 150mm deep and thermostatically controlled to 60°C ± 1°C. The tank should have a perforated false bottom or be equipped with a shelf suspending specimens at least 50mm. Figure 6 shows the laboratory apparatus and testing.

3. Results and Discussion

3.1. General

In this study, there were forty-four sets of bituminous mix used for different types of mineral ingredients as a filler and investigated using the method of Marshal Mix design. The mixtures composed of crushed stone aggregates and natural subbase dust (NSD) fillers with varying contents of asphalt binder by the total mixture and their effect on Marshal properties assessed thoroughly.

Literature reviews showed different research had already been conducted on the effect of fillers on bituminous mixtures that revealed a type and amount of fillers affect the performance of hot mix asphalt (HMA). The test results obtained in this research are discussed under the following subsequent sections.

3.2. Interpretation of Test Data

3.2.1. Aggregate Gradation of Mix Design

The hot mix asphalt (HMA) is graded by the percentage of different aggregate particle sizes they contain. (Table 5) illustrated HMA gradations without a natural subbase dust filler, which is the normal gradation used as a control mix for the study. Certain terms used for referring the aggregate fractions and filler are: Course aggregate, G-1 ¾ inches, Intermediate Aggregate, G-2, 3/8 inch, Fine Aggregate, G-3, and Mineral Filler, G-4. Blending proportion for the mixture without NSD filler are G-1 = 32%, G-2 = 23% and G-3, = 45% by weight of the total mixture.

Figure 7 shows the gradation of aggregates without NSD filler, and from the graph, it can be concluded that the mixture needs blending with natural subbase dust (NSD) filler material to achieve the grading requirements as per the lower and upper specification limits.

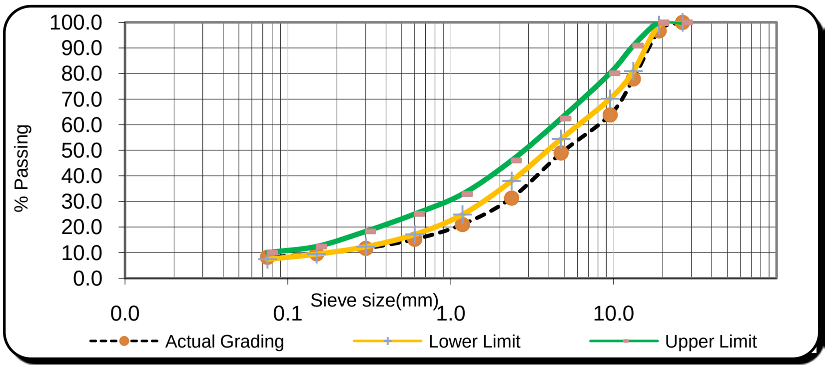


Figure 7. Gradation of Aggregate "without" Filler Material

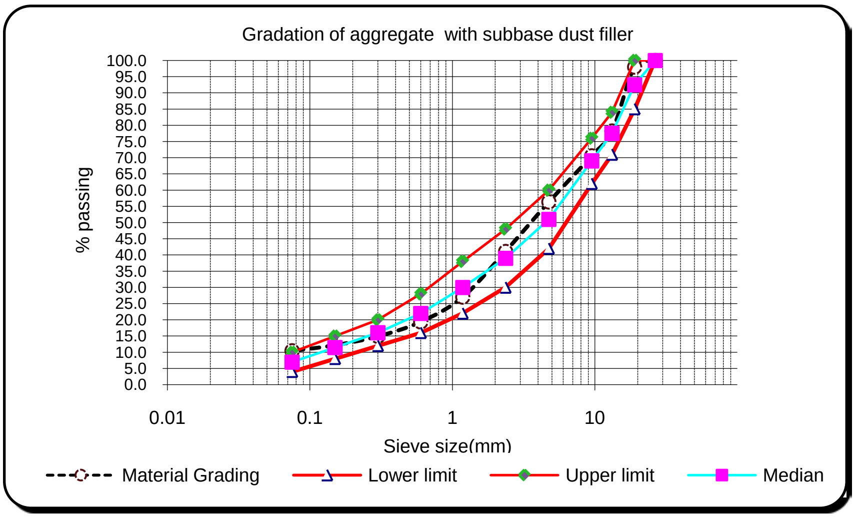


Figure 8. Gradation of Aggregate "with" Natural Subbase Dust Filler

Figure 8 shows the gradation of aggregates with natural subbase dust filler. The upper and lower limit of the gradation indicated, in the job mix of G-4 at 6% of natural subbase dust, and the aggregates at a proportion of G-1 at 26%, G-2 at 22%, and G-3 at 46% have resulted in good blending for the Marshall mix design process.

3.3. Aggregate Physical Properties

The physical properties of the aggregates and their suitability in road construction conducted. The results are indicated in Table 4. The specific surface area for each aggregate size distribution determined by multiplying surface area factors by the percentage passing the various sieve sizes and adding together. As can be seen from the results, as the filler content increases, the specific surface area also increases.

3.4. Asphalt Binder Test Results

Tests conducted on a sample including penetration, specific gravity, softening point, flash point, ductility, and solubility, performed for basic characterization properties of penetration grade asphalt. The test results are shown below in Table 5, which complied with the requirement of Ethiopian Road Authority (ERA) Standard Specifications.

Table 6 shows the specific gravity values of different filler materials used for the control mix and reference of the experiment works.

3.5. Natural Subbase Dust Filler

The filler used in the current study namely screened and pulverized natural subbase material obtained from the natural quarry site found in the study. The physical properties affecting the bituminous mixture property, such as gradation parameters and Plasticity index, were determined, as shown in Table 7.

3.6. Optimum Bitumen Content

The asphalt mix tested by the Marshall method to examine the samples with different percentages of bitumen content composed of 4.0, 4.5, 5.0, 5.5, and 6.0%. From the laboratory test results, it was found out a 5.1% optimum bitumen content.

3.7. Marshall Test Results

The laboratory tests result for the Marshall test of the mixtures with different binder content are presented in Table 7 & Table 8. The binder content and the mixture properties relationships such as Stability, VFB, Flow, VMA, VA, and Bulk Density are presented in Figures (15 - 20). Sets of forty-four samples each weighing 1200 gram prepared using five different bitumen contents of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0% [14] by the total mass of the sample to find the optimum bitumen amount.

Table 4. Aggregate Physical Properties

No	Test Description	Test Method			Result	Specification (ERA Manual 2002)
		ASTM	AASHTO	BS		
1	Los Angeles Abrasion, %	AASHTO T 96			14.25	< 30
2	Aggregate Crushing Value, ACV, %	BS 812 part 104			16.7	<25
3	Durability and Soundness, %	ASTM C 128			5.5	<12
4	Coarse Aggregate Specific, Gravity (Bulk)(kg/m^3)	AASHTO T 85			2.72	N/A
5	Fine Aggregate Specific Gravity (Bulk)(kg/m^3)	AASHTO T 84			2.59	N/A
6	Coarse Aggregate Specific Gravity (Apparent)(kg/m^3)	AASHTO T 85			2.86	N/A
7	Fine Aggregate Specific Gravity (Apparent)(kg/m^3)	AASHTO T 84			2.87	N/A
8	Water Absorption, %	ASTM C 127			1.71	<2
9	Particle shape, Flakiness, %	BS 812, Part 110			24.9	<45

Table 5. Physical Properties of used Bitumen

No	Test Description	Unit	Test Method	Test Result	Specification Limit
1	Penetration @25°C	1/10mm	ASTM D5-06	90	85 -100
2	Specific gravity @25°C	kg/cm^3	ASTM D70	1023	1020
3	Ductility@25 °C	cm	ASTM D113-86	100+	100+
4	Solubility	%	ASTM D2042	99.6	Min. 99
5	Softening Point	°C	ASTM D36	46.4	42 -52
6	Fire Point	°C	ASTM D92-90	23	Max. 100
7	Flash Point	°C	ASTM D92-90	562	Min. 232

Table 6. Filler Materials Used for Control Mix and Reference

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 7. Laboratory Test Result for Natural Subbase Dust 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

NP= Non-Plastic.

Table 8. Summary Marshall Test Result for Mixes with 0% Filler

% AC	Trial	Specimen Mass (gm)			Bulk Vol, cc	Bulk S.G	Max. S.G. (Loose Mix)	Unit Wt, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow (mm)
		In Air	In Water	SSD In Air								Measured, div	Factor	Adjusted,kN	
4.0	A	1165.0	665.3	1170.5	505.2	2.306	2.571	2.306	10.3	17.89	42.4	1080.0	0.93	12.32	4.40
4.0	B	1166.5	661.0	1167.0	506.0	2.305	2.571	2.305	10.3	17.92	42.5	1150.0	0.93	13.12	4.70
4.0	C	1155.5	657.0	1156.5	499.5	2.313	2.571	2.313	10.0	17.64	43.3	1003.0	0.93	11.45	3.40
Average						2.308	2.571	2.308	10.2	17.82	42.7			12.30	4.17
4.5	A	1198.5	687.5	1200.0	512.5	2.339	2.525	2.339	7.4	17.15	56.8	1050.0	1.04	13.40	3.50
4.5	B	1174.0	680.0	1178.5	498.5	2.355	2.525	2.355	6.7	16.58	59.6	859.0	1.04	10.96	3.40
4.5	C	1168.0	665.0	1168.5	503.5	2.320	2.525	2.320	8.1	17.82	54.5	1021.0	1.04	13.03	4.00
Average						2.338	2.525	2.338	7.4	17.18	56.9			12.46	3.63
5.0	A	1148.0	658.0	1150.5	492.5	2.331	2.502	2.331	6.8	17.86	61.9	890.0	1.04	11.36	3.95
5.0	B	1179.5	685.4	1182.0	496.6	2.375	2.502	2.375	5.1	16.31	68.7	860.0	1.04	10.97	3.60
5.0	C	1188.5	689.0	1190.0	501.0	2.372	2.502	2.372	5.2	16.42	68.3	859.0	1.04	10.96	3.50
Average						2.359	2.502	2.359	5.7	16.86	66.2			11.10	3.68
5.5	A	1153.0	666.0	1154.0	488.0	2.363	2.470	2.363	4.3	17.17	75.0	652.0	1.09	8.72	3.52
5.5	B	1177.5	689.5	1180.0	490.5	2.401	2.470	2.401	2.8	15.84	82.3	738.0	1.09	9.87	4.30
5.5	C	1191.5	700.5	1192.0	491.5	2.424	2.470	2.424	1.9	15.03	87.4	654.0	1.09	8.75	4.00
Average						2.396	2.470	2.396	3.0	16.02	81.3			9.11	3.94
6.0	A	1188.0	691.0	1189.0	498.0	2.386	2.464	2.386	3.2	16.81	81.0	804.0	1.04	10.26	5.20
6.0	B	1179.5	687.0	1180.0	493.0	2.392	2.464	2.392	2.9	16.60	82.5	945.0	1.04	12.06	5.90
6.0	C	1191.0	692.1	1196.0	503.9	2.364	2.464	2.364	4.1	17.58	76.7	1070.0	1.04	13.65	4.00
Average						2.381	2.464	2.381	3.4	16.99	80.0			11.99	5.03

Where; Gmb= Bulk specific gravity, Gmm= Theoretical maximum specific gravity, Va= Air Void in the total mix, VMA= Voids in the Mineral Aggregate, & VFA% = % Voids Filled with Asphalt.

The process of obtaining the stability values from the standard 63.5mm thickness was converted to an equivalent 63.5mm value by means of a conversion factor. The conversion was made on the basis of either measured thickness or measured volume.

Table 8 shows the laboratory test results of mixtures without filler material and the corresponding values of Marshall properties with different bitumen contents.

Likewise, Table 9 & Table 10 indicated the laboratory test results of mixtures with filler material and the corresponding values of Marshall properties with different bitumen contents. And the summary of the Marshall test results "without" and "with" filler materials are presented in Table 11 below.

Table 9. Marshall Properties of Bituminous and Aggregates size with 6% NSD Filler

Marshall Properties of Bituminous Mixtures					
Description	Aggregate Size				
	G1, 3/4mm	G2, 3/8mm	G3, Fine	G4, Filler	
Blending proportion, %	26	22	46	6	100
Bulk Specific Gravity of each	2.59	2.62	2.79	2.683	
Bulk Specific Gravity of Total Aggregate, Gsb					2.691

Table 10. Summary Marshall Test Result for Mixes with 6% NSD Filler

	Trial	Specimen Mass (gm)			Bulk Vol, cc	Bulk S.G of Speci. (Gmb)	Max. S.G. (Gmm)	Unit Wt, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow (mm)
		In Air	In Water	SSD in Air								Measured, div	Factor	Adjusted, kN	
4.0	A	1181.5	663.0	1184.0	521.0	2.268	2.569	2.268	11.7	19.09	38.7	1252.0	1.04	16.50	3.40
4.0	B	1176.0	663.5	1177.5	514.0	2.288	2.569	2.288	10.9	18.38	40.7	1417.0	1.04	18.67	4.00
4.0	C	1154.5	655.0	1157.0	502.0	2.300	2.569	2.300	10.5	17.95	41.5	1361.0	1.04	17.93	3.30
Average						2.285	2.569	2.285	11.0	18.47	40.5			17.70	3.57
4.5	A	1184.5	668.5	1186.0	517.5	2.289	2.562	2.289	10.6	18.77	43.5	1220.0	1	15.46	3.60
4.5	B	1180.5	667.0	1182.5	515.5	2.290	2.562	2.290	10.6	18.73	43.4	890.0	1	11.28	3.85
4.5	C	1188.5	669.5	1190.0	520.5	2.283	2.562	2.283	10.9	18.98	42.6	890.0	1	11.28	4.00
Average						2.287	2.562	2.287	10.7	18.83	43.2			12.67	3.82
5.0	A	1178.5	668.0	1181.0	513.0	2.297	2.498	2.297	8.0	18.91	57.7	813.0	1	10.30	4.00
5.0	B	1174.5	669.0	1179.0	510.0	2.303	2.498	2.303	7.8	18.70	58.3	1029.0	1	13.04	4.00
5.0	C	1195.0	682.0	1198.0	516.0	2.316	2.498	2.316	7.3	18.24	60.0	1149.0	1	14.56	4.50
Average						2.305	2.498	2.305	7.7	18.62	58.6			12.63	4.17
5.5	A	1189.0	682.0	1190.5	508.5	2.338	2.479	2.338	5.7	17.90	68.1	881.0	1.04	11.61	4.00
5.5	B	1188.0	682.5	1198.0	515.5	2.305	2.479	2.305	7.0	19.06	63.3	783.0	1.04	10.32	3.52
5.5	C	1196.5	695.0	1197.0	502.0	2.383	2.479	2.383	3.9	16.32	76.1	1060.0	1.04	13.97	4.00
Average						2.342	2.479	2.342	5.5	17.76	69.0			11.96	3.84
6.0	A	1183.0	673.5	1183.5	510.0	2.320	2.448	2.320	5.2	18.96	72.6	806.0	1.04	10.62	4.80
6.0	B	1192.5	687.0	1193.5	506.5	2.354	2.448	2.354	3.8	17.77	78.6	795.0	1.04	10.48	4.00
6.0	C	1203.0	696.0	1204.0	508.0	2.368	2.448	2.368	3.2	17.28	81.5	610.0	1.04	8.04	5.00
Average						2.347	2.448	2.347	4.1	18.00	77.2			9.71	4.60

Note: Compaction = 75 Blows, AC Grade = 85/100, Specific Gravity of AC = 1.010.

Table 11. Summary of Marshall Test Results “with” and “without” filler materials

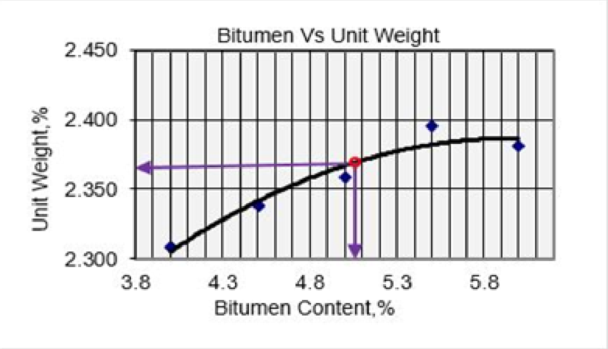
AC content (%)	Unit Wt (Mg/m^3)		Air Void, (%)		VMA (%)		VFB (%)		Corrected Stability (KN)		Flow (mm)	
	A	B	A	B	A	B	A	B	A	B	A	B
4	2.308	2.285	10.2	11.0	17.82	18.47	42.7	40.5	12.30	17.7	4.17	3.57
4.5	2.338	2.287	7.4	10.7	17.18	18.83	56.9	43.2	12.46	12.67	3.63	3.82
5	2.359	2.305	5.7	7.7	16.86	18.62	66.2	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	14.50	80.0	77.2	11.99	9.71	5.03	4.60

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

3.8. Marshall Stability

Stability is generally a measure of the mass viscosity of the aggregate-asphalt cement mixture. It is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement. The stability of the specimen is the required maximum allowable load to produce an unsatisfactory sample when the load applied at a constant rate of 50mm / min. From Figure 9 below, it is noticed that the maximum stability of the asphalt mix is 13.75kN at 5.1% bitumen content.

The addition of natural subbase dust (NSD) filler in the asphalt mix reduced the deformation may be due to hot temperatures, especially during its early life, when it is most susceptible to rutting. Further, the filler made the hot mix asphalt (HMA) less sensitive to moisture content effect by improving the aggregate-bitumen bonding. The use of filler ingredients in the hot asphalt mix has resulted in void and asphalt content values to decrease. So, a decreasing asphalt content by adding natural subbase filler resulted in high stability by avoiding rutting, flushing, and bleeding effects.



Bitumen Content = 5.1%

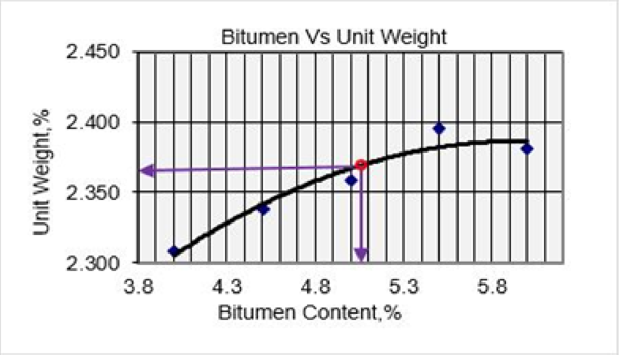
Unit Wt = 2.347%

Figure 9. Stability Vs. Bitumen Content

The aim of the stability test measures the mix resistance to deformation under load. Figure 10 above illustrates the addition of natural subbase filler on the blend resulted in increasing the stability. This is due to the combination of NSD filler and asphalt cement in the mix acting as a more viscous binder. Therefore, the natural subbase filler has stiffened the asphalt film and reinforced it. That means a mixture with NSD filler had good resistance of deformation than that of blended without filler.

3.9. Unit Weight (Density)

The compacted asphalt mix' density is the unit weight of how mixed asphalt. Meeting the minimum density per AASTO or Ethiopian Road Authority (ERA) Specifications is very important for the pavement performance within its design life. Mix properties are necessary to be calculated in the weight and volume of the sample. The combination of NSD filler and asphalt cement act ed as a more viscous binder, increasing the Marshall stability. As filler content increased in the mix, it has filled the voids increasing the unit weight too. However, at higher content, the mix became stiffer that needs more significant compaction effort then consequently lower dense mixture obtained. From Figure 10 below, it is obtained that the maximum unit weight was 2.347% at 5.1% bitumen content.



Bitumen Content = 5.1%

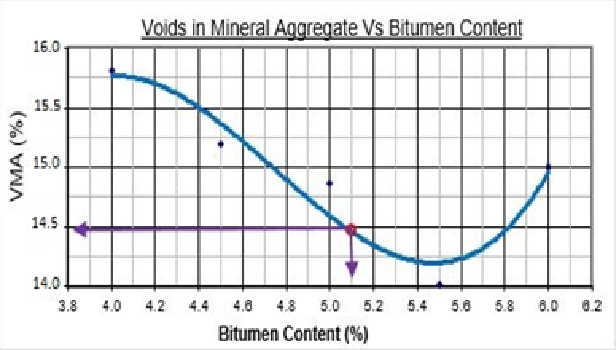
Unit Wt = 2.347%

Figure 10. Unit Weight Vs. Bitumen Content

3.10. Voids in Mineral Aggregate (VMA)

The Voids in the Mineral aggregate are defined as the inter-granular void space between the interstices of aggregates in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percentage of the total amount in volume. From Figure 11 below, it is noticed that the VMA decreased gradually as bitumen content increased.

It is common that as filler content in the mix increases, the voids in mineral aggregate decreases up to minimum value then increases at higher filler content. The figure below shows the mixtures blended with natural subbase dust filler exhibited in a similar manner. It indicated the result of VMA with different bitumen content.



Bitumen Content = 5.1%

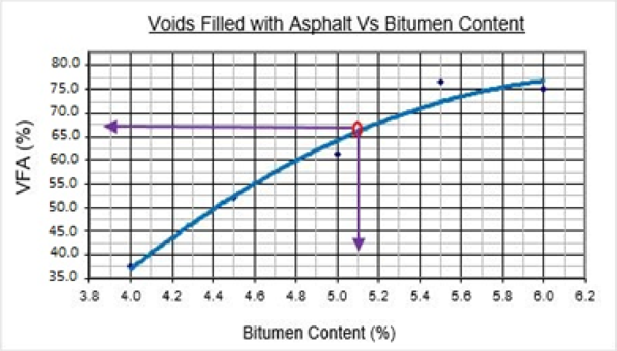
VMA = 14.50%

Figure 11. VMA Vs Bitumen Content

3.11. Voids Filled with Asphalt (VFA)

The amount of the inter-granular void space between the aggregate particles is called Voids filled with asphalt (VFA). From Figure 12, it could be noticed that the percentage of VFB increases gradually as bitumen content increases also, which was due to the increase of voids amount filled with bitumen in the asphalt mix.

The VFA represents the amount of effective bitumen in the asphalt mix. The result is inversely related to air voids; hence, as air voids decrease, the VFA increases. But from the result, it can be concluded that the addition of NSD filler on the bituminous mixture has changed the trend from inverse to reveres resulting in the decrease of both air void and asphalt content. The figure shows the results of VFB at different bitumen content.



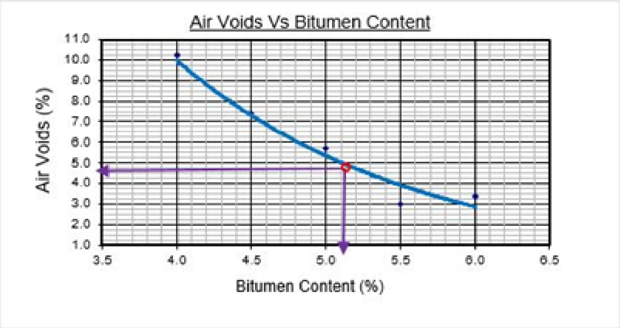
Bitumen Content = 5.1%

VFA = 68.70%

Figure 12. VFA Vs Bitumen Content

3.12. Air Voids Content (Va)

The air voids (Va) is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. It was expressed as a percentage of the bulk volume of the compacted paving mixture. From Figure 13 below, the air voids content gradually decreases with increasing the bitumen content, and that is due to the increase of voids percentage filled with bitumen in the asphalt mix. The figure below shows the results of air voids content with different bitumen content.

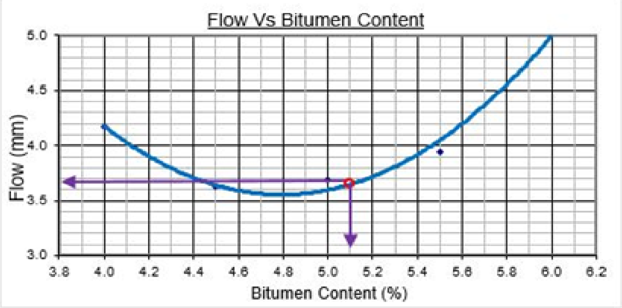


Bitumen Content = 5.1%	
Air Void = 4.5%	

Figure 13. Air Void Vs. Bitumen Content

3.13. Flow of Bitumen

Flow is the total amount of deformation, which occurs at the maximum load. From Figure 14 below, the maximum flow of the asphalt mix obtained at 6 .0% bitumen content. High flow values generally indicate a plastic mix that will experience permanent deformation under traffic. In contrast, low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability. They may experience premature cracking due to mixture brittleness during the life of the pavement. The figure below shows bitumen flow results with different bitumen contents.



Bitumen Content = 5.1%	
Flow (mm) = 3.70mm	

Figure 14. Flow Vs. Bitumen

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

3.14. Determination of Optimum Asphalt Content

The effective asphalt content helped to provide better performance of the mixtures, which creates the asphalt film around the interstices of the aggregates. If the asphalt film thickness around the interstices of the aggregate thickened enough, few wanted characteristics such as good durability, more fatigue resistance, and higher resistance to moisture-induced damage could be achieved from bituminous mixtures. But there should be a maximum limit were upon an increase in the degree of hotness or coldness as well as axle loadings, the asphalt amount in the mix increased and resulted in bleeding on the outer surface of paved road. On the other hand, it could be stated that as the adequate asphalt amount decreases, the filler content increases in the hot mix asphalt. The scenarios explain that it was due to the number of voids filled with mineral ingredients as the filler amount in the mix increased, resulting in a smaller amount of the total bitumen. Likewise, as the filler content increases, the more asphalt could be enwrapped by the fine aggregates resulted from the higher proportion of finer aggregates in the mixture. Table 12 shows the range for the ERA specifications to compare with the Marshall mix results with and without filler materials.

In Table 13 illustrated the Marshall properties of the mixes corresponding to filler content for the control mix as well as mix modified with natural subbase dust (NSD) filler. The sources of all materials and aggregate gradation were the same for all the mixes, and the changes in all properties obtained were attributed to the type of filler and their contents only.

3.15. The relationship of Marshall Properties with Natural Subbase Dust (NSD) Filler Material

3.15.1. Marshall Stability - NSD Filler Content Relationship

From Figure 16 below, it is observed that all values of stability with different filler content have achieved the specification requirements. As shown below, the stability of mixes with natural subbase dust (NSD) has increased as the filler content increases till it reaches the maximum stability that was 13.75kN at 6% filler content, then it started to decline.

3.15.2. Flow - NSD Filler Content Relationship

The flow of mixes with 6% NSD filler has a value of 3.66mm, and it is within the range of the specifications. Figure 16 shows the flow value results of HMA at different filler content.

Table 12. Comparison between the Marshall Test Results and the ERA

Marshall Mix Properties	Stability (kN)	Flow (mm)	VFB (%)	VMA (%)	Va (%)	Density (g/cm^3)	OBC (%)
Mix Criteria (ERA Specification)	8 (min.)	2-4	65 -75	10 -16	3- 6	-	4 -8
Mix "Without" Filler	10.2	3.7	70.5	16.5	5.0	2.317	5.1
Mix "With" 6% NSD Filler	13.90	3.66	68.7	14.5	4.50	2.392	5.1

Table 13. Marshall Test Results for Types of Fillers to OBC at Various Filler Content

Filler Type	Filler (%)	OBC (%)	Air Void (%)	VMA (%)	VFB (%)	Corrected Stability (kN)	Flow (mm)
HL	2	5.1	6.40	15.90	58.70	10.80	3.01
OPC	2	5.1	5.90	15.80	62.5	11.50	3.20
Marble Dust	4	5.1	4.80	16.50	70.50	10.20	3.70
Natural subbase dust filler	0	5.1	7.80	17.10	54.30	10.20	2.80
	2	5.1	6.40	16.10	60.20	10.70	3.24
	4	5.1	5.60	14.8	62.30	10.90	3.17
	6	5.1	4.50	14.5	68.70	13.90	3.66
	8	5.1	3.70	12.6	70.40	10.70	3.61

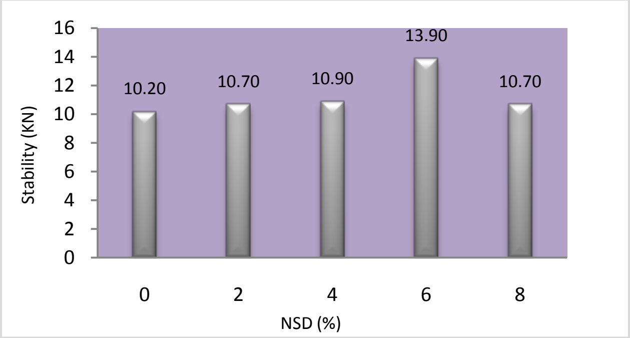


Figure 15. Asphalt Mix Stability - Filler Content Relationship

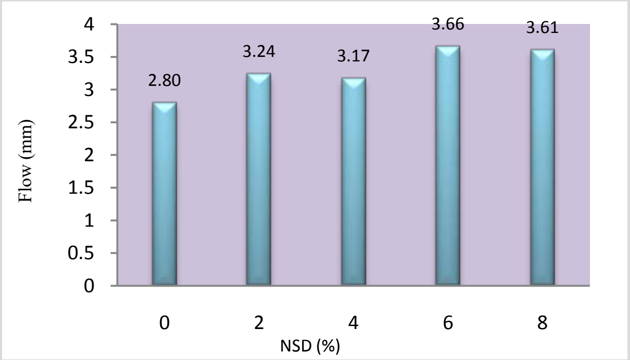


Figure 16. Asphalt Mix Flow - Filler Content Relationship

3.15.3. Bulk Density - NSD Filler Content Relationship

The bulk density of HMA mixes with different percentages of NSD filler content achieves the specification requirements. The value of bulk density at 6% natural subbase dust (NSD) filler was 2.392g/cm^3. The general trend of the chart indicated the bulk density increases as the filler content increases, as can be seen in Figure 17.

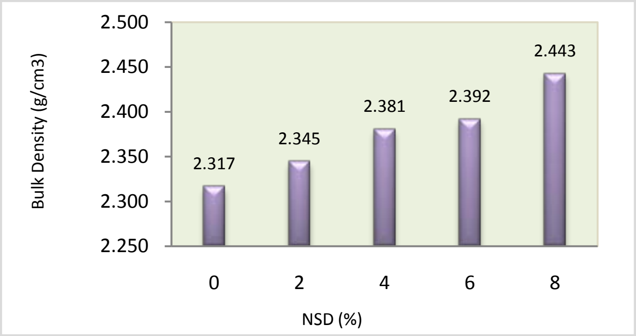


Figure 17. Bulk Density of Asphalt Mix - Filler Content Relationship

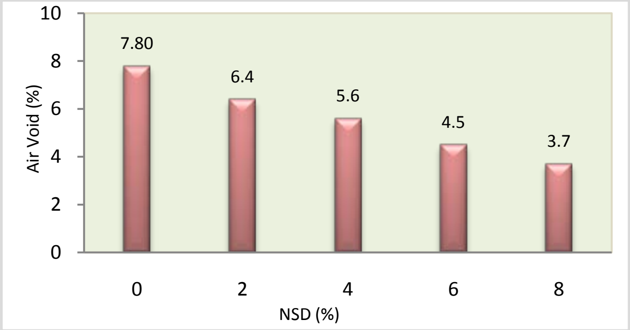


Figure 18. Air Voids Asphalt Mix Air Voids - Filler Content Relationship

3.15.4. Air Voids (Va) - NSD Filler Content Relationship

Figure 18 shows the air voids' value of the mixes decreased gradually as the NSD filler content increases. The figure illustrated that at 6 % filler content, the air voids percentage was 4.5%, which is the median value of the specification.

3.16. Optimum Filler Content

Based on the results, all values of Marshall stability for different filler content met the minimum requirements as per the Standard Specifications, which has a minimum value of 10.15kN, and maximum stability value of 13.75kN at 6% natural subbase dust (NSD) filler content. The air voids showed 4.50% when tested at 6% filler content. It means the value is very close to the median air voids of 4.5%, based in the Specifications, as shown in Table 12. On the other hand, all values of bulk density at different filler content are close to each other. These values are pursuant to the requirements of the standard specification.

4. Conclusion

The focus of the study was to evaluate the potential use of screened and pulverized natural subbase as alternative filler material in the characteristics of hot mix asphalt. Based on the findings of the laboratory investigation, the following conclusions are drawn:

The property of the natural subbase dust as filler material showed an excellent potential sign that it could be used for hot asphalt mix concrete production. The investigation of natural subbase dust filler resulted in satisfactory effects on the Marshall properties of the asphalt mixture. On the other hand, a comparison of natural subbase dust filler with the conventional fillers indicated that based on the Ethiopian Road Authority (ERA) and AASHTO Standard Specifications satisfied all the requirements for hot mix asphalt concrete production. Further, the outcome of Marshall parameters like Stability, Air voids, and Bulk density values showed a consistent result with the standard specifications at 6 % natural subbase dust filler content. Therefore, the natural subbase dust filler can potentially be used in hot mix asphalt concrete production with an optimum content of 6% by addressing issues like cost, abundance, and accessibility in the construction project site.

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