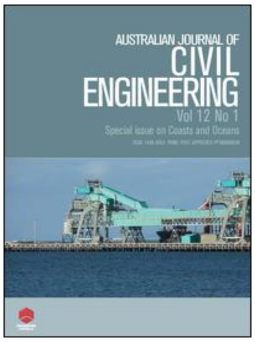

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ARTICLE

Evaluation of the HMA performance using combined effects of marble waste dust filler and superpave aggregate gradation

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ABSTRACT

During the fabrication of new products, a variety of wastes discharged and stored by causing harsh environmental problems. The marble processing plant is amongst the industrial sector that produces huge waste. Thus, the main purpose of this study is to evaluate the combined effects of marble waste dust filler and Superpave aggregate gradation on the performance of HMA. Based on the Marshall Mix design, seventy-two (72) specimens were produced from three below-restricted zone (BRZ) of Superpave gradation (BRZ4, BRZ5, & BRZ6) by using the 0.45 power chart. The design gradation obtained to be BRZ5 with 4.96% OBC with corresponding values 9.13 KN of stability, 2.96 mm of flow, 73.51% of VFA, 15.73% of VMA, 2.308 gm/cm^3, of bulk density and 4% of air void. The crushed stone dust filler was partially replaced by Marble Waste Dust filler (under No. 200 sieve) at replacement rate of (1%, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5%) by keeping design gradation and OBC constant. The test showed satisfactory results. The Marshall mix design parameters of all mixtures are within specification limit under international and local specifications. Marble waste dust filler when blended with a BRZ of Superpave gradation indicated a substantial effect on Marshall stability with 10.18 KN value at 3% MWD filler content.

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Hot Mix Asphalt; superpave aggregate gradation; marble waste dust filler; HMA performance; crushed stone dust filler

1. Introduction

Rapid urbanisation, together with growth in population along with technological development and industrialisation, is causing huge environmental problems. This, in turn, causes an increase in production, which led to the massive disposal of waste materials. During the fabrication of new products, a variety of wastes discharged and stored by causing harsh environmental problems such as devastation and reduction of natural resources, and environmental pollution. however, Waste could be reused to prepare new products or as a replacement for existing conventional materials especially in pavement construction. Waste material utilisation decreases the need for natural resources and therefore protects environmental destruction while concurrently decrease the effects of waste disposal and storage problems on the environment (Akbulut. et al. 2012).

Among the mining sectors, the marble processing plant is one of the important industrial sectors. There are more than 14 marble processing plants in Ethiopia located in different towns. In Ethiopia 409,374.00, 572,421.00, 613,820.00, 770,000.00 and 1,000,000.00 m^2 of marble commodities were produced in the year 2009, 2010,2011, 2012 and 2013 respectively. Totally, 3,365,615 metric square of marble commodities were produced from the year 2009 to 2013. This implies that the amount of marble waste is increasing as more marble processing companies are producing more amount of marble block. Thus, disposal of MWD will cause various environmental and health problems (Yager 2016). As more companies joined the industry, the production of marble commodities in conjunction with the quantity of marble waste dust formed as a result of cutting and polishing processes increased than before in our country. This waste is rarely degradable and will cause serious environmental problems such as waterlogging, reduces the porosity of soils, and increases the alkalinity of soils, which results in soil fertility and other health problems (Shafi et al. 2017). Thus, utilising the waste/byproduct materials in highway pavement could be helpful in terms of reusing wastes.

Globally a significant increase in demand for using waste materials in pavement construction, are noticeable particularly as mineral filler. The mineral filler passing through sieve number 200 mesh or 0.075 mm opening sieve is a significant component of the asphalt mixture as it plays a great role in the hot mix asphalt because they fill voids and improve the cohesion of asphalt binder. However, the quantity and type of filler in the asphalt mix considerably affect the bond

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between the aggregate and bitumen (Choudhary, Kumar, and Gupta 2018).

Marble waste dust is one type of industrial byproduct of materials that can be reused. It is the waste created during the cutting, shaping, and polishing of the marble processing plants. From previous conducted studies, the possibility of using marble waste dust as filler substitute in hot asphalt mixtures is confirmed, and promising results showed with improved properties (Eisa., Basiouny., and Youssef. 2018). However, the actual use of marble waste (MWD) filler has not been known as an alternative filler in local road construction, and the effects of MWD filler, when combined with Superpave aggregates gradation, is unidentified.

Additionally, gradation is greatly affected the performance of HMA mixtures, including air void, stability, stiffness, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage (Abukhettala 2006). This implies that aggregate gradation significantly influences the performance of HMA. Superpave aggregate gradation is known with it is introducing the restrict zone to aggregate gradation. The restricted zone (RZ) is that the area of the FHWA's 0.45 power chart in Superpave specifications through which aggregate gradations are not permitted to pass through and control points through which the blended mixture gradation must pass (Asphalt Institute 1996).

In local particle size distribution of aggregate gradation, upper and lower bound set for most sizes. The limits incline to produce a finer gradation as per Superpave specification (i.e. gradation that pass above MDL of Superpave). This implies a coarser gradation which is below restricted zone (coarser gradation) is still not utilised in ERA specification. So it is needed to investigate the effects BRZ gradation on HMA Marshall properties. As the study carried out on the assessment of the influence of Superpave aggregate gradation on Marshall design method parameters of wearing course, the Superpave specified gradation could be used as a guided to select aggregate gradation for wearing course in Marshall mix design without significant effect (W. K. M. &. P. Fernando 2012).

Currently, the actual usage of marble byproducts/waste is very limited and has not been recognised as an alternative filler in local pavement construction. Also, the usage of marble by-products/waste dust filler in HMA mixture, particularly with different aggregate gradation and percentages, are not properly established when it comes to sieve sizes using 0.45 power charts Superpave aggregate gradation. Therefore, this study was undertaken through laboratory tests to evaluate the Marshall properties of the bituminous mixture using the marble waste dust filler combined with Superpave aggregate gradation.

Generally, the goals of this study are to evaluate the effects of below restricted zone of Superpave aggregate gradation from the sieve 0.45 power chart on the Marshall properties of hot mix asphalt, to identify the effect of different percentage of marble waste dust filler when combined with Superpave aggregate gradation on the performance HMA and to determine the best replacement percentage of waste marble dust filler to be added with Superpave gradation in hot mix asphalt.

2. Materials and research methodology

2.1 Materials

Aggregate samples for the proposed HMA mix design are obtained from ERCC (Ethiopian road Construction Corporation) quarry located at Deneba site 81 km from Jimma town. The site is selected from the angle of the good quality material representation. The crushed stone filler is also brought from the same source as of aggregate. Bitumen 60/70 penetration grade is also obtained from ERCC, the same project site, whereas marble waste dust filler is collected from the Ethiopian Marble Processing Enterprise, which locates in Addis Ababa.

2.2 Tests on materials

Preparation of asphalt ingredients such as aggregate, asphalt binder, and marble waste dust are started with quality tests. The individual ingredients of the mixture are tested in the laboratory to decide if they meet the specified requirement or not. Different material quality tests were performed as per set by AASHTO, ASTM, and BS standards. The quality tests which were carried out on aggregate, including mineral filler, were sieve analysis (gradation), aggregate crushing value, Los Angles abrasion, aggregate impact value, and specific gravity and water absorption test. Besides, bitumen quality tests, namely specific gravity, softening point, ductility, penetration, and flash point, were conducted to determine its quality.

2.2.1 Physical properties mineral filler

The filler is one of the ingredients of asphalt mixture and material which passes 0.075 mm sieve opening or sieve No. 200 mesh. The effects of filler on the mechanical properties of the asphalt mixture are remarkable as it is one of the crucial ingredients in the HMA mixture. Fillers, as one of the ingredients in an HMA mixture, plays a vital role in determining the performance and properties of mixes, especially its interlocking and binding effects (Zulkati, Diew, and Delai 2012). In this study, marble waste dust and crushed dust which pass through No. 200 mesh were used as mineral filler in the preparation HMA mixture. Also, their physical properties, which are expected to be critical in affecting the HMA mix property such as plasticity index and gradation, were tested in the laboratory. Table 1 shows laboratory test results of marble waste dust filler.

2.2.2 Mineral aggregate tests and preparation

Before starting mix design, aggregate quality tests were carried out and compared with the specification set on different standard specifications like AASHTO, ASTM, BS, and ERA 2002. The output of the quality tests is presented below in Table 2.

2.2.3 Combined gradation of mineral aggregates

In the HMA mixture preparation, design gradation is one of the most substantial parameters in determining the properties and quality of the mixture. Prior to mix production, the aggregates size distribution should have to be determined. Aggregates were sieved into required sizes and recombined to meet the design gradation. In this study, Superpave gradation was used to prepare the Marshall mix design. The plotting of the aggregate particle distribution differs from the conventional graph, and it is drawn on the 0.45 power chart. The adopted aggregate blending gradations are presented below in figure 1, figure 2, and figure 3. The blended aggregate gradations are designated as BRZ4, BRZ5, and BRZ6, which describe below the restricted zone of Superpave gradation with 4%, 5%, and 6% crushed stone filler proportion, respectively.

2.2.4 Asphalt binder selection and test

Prior to mix design and preparation of hot mix asphalt, different bitumen quality tests like penetration, ductility, specific gravity, softening point, and flash point were done to determine the quality of asphalt binder or bitumen to identify its suitability. Furthermore, the results of bitumen quality tests are presented in Table 3.

As it can be observed from the above table, the physical properties of bitumen 60/70 are met the required specification standards.

3. Results and discussion

3.1 Marshall test results and discussion

The test results of asphalt mixture samples, which are produced from three different BRZ Superpave gradations by varying conventional filler proportion specifically 4%, 5%, and 6% by the total mass of aggregate, with varying bitumen contents to determine design gradation.

The purpose of preparing these mixes were to evaluate the effects BRZ gradation on Marshall parameters as well as to obtain design bitumen content, optimum filler proportion, and to select design aggregate based on maximum stability. Marshall test results of the mixtures with various bitumen content with three Superpave gradation BRZ4, BRZ5, and BRZ6 are shown in Tables 4–6. The local Marshall design standards for heavy traffic, minimum stability of 7.0 kN at 60°C, flow value should be ranged between 2 mm to 4 mm, percentage of Air voids should be ranged between 3 and 5%, a minimum value of VMA corresponding to 4% Va, with nominal maximum particle size of 19 mm should be 13, and VFB should be ranged between 65 and 75% (ERA, Pavement Design Manual 2002).

3.2 Determining optimum bitumen content

The optimum bitumen content was determined as the value of bitumen contents corresponding to the median of the 4-% air voids (Roberts et al. 1996). This procedure of calculating bitumen content is known to be a NAPA (National Asphalt Pavement Association) procedure. This method involves some procedures: first bitumen contents at the midpoint of air voids, specifically 4%, were determined. Next, Marshall stability, flow, VMA, and VFA at this optimum bitumen content are determined from the plotted curves of bitumen content versus design parameters. Finally, the determined values of all design parameters are compared with the ERA

Table 1. Physical properties of marble waste dust filler.

No.	Test description	Test Methods		Result	ERA specification
		AASHTO	ASTM		
1	Plastic Index, (PI)	T89 or T90	D 423 or 424	Np	≤ 4
2	Specific gravity (kg/m3)	T 100 or 104	D 854 or C 88	2.697	-

Table 2. Physical properties aggregate.

Tests	Test Method	Test Results		Specification requirement as per ERA 2002
		Coarse Aggregate	Fine Aggregate	
Bulk dry S.G	AASHTO T 85–91	2.585	2.514	-
Bulk SSD S.G		2.621	2.583	-
Apparent S.G		2.681	2.628	-
Water absorption, %	BS 812, part 2	1.38	1.38	<2
Flakiness Index	BS 812 part 105	19		<45
Los Angeles Abrasion(LAA),%	AASHTO T 96	11.85		<35
Aggregate Crushing Value (ACV), %	BS 812 part 110	14.9		<25
Aggregate Impact Value (AIV), %	BS 812 part 112	6.32		<25

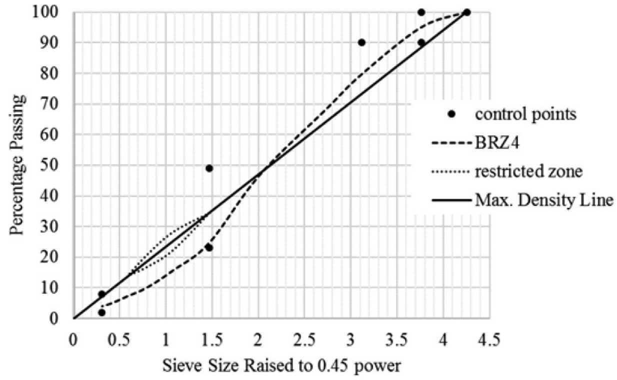

Figure 1. Superpave gradation using 0.45 power chart for BRZ4 mix.

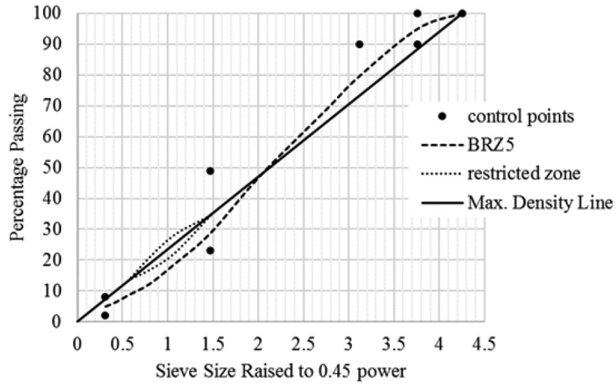

Figure 2. Superpave gradation using 0.45 power chart for BRZ5 mix.

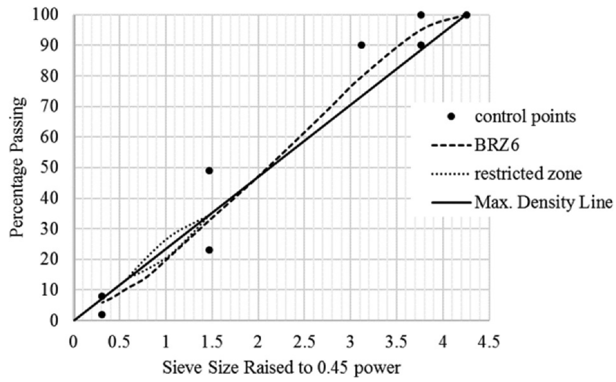

Figure 3. Superpave gradation using 0.45 power chart for BRZ6 mix.

specification for acceptability. According to test results, optimum bitumen contents is obtained to be 4.96% corresponding to BRZ5 gradations with 5% of crushed stone dust filler. By comparing all the Marshall parameters of mixtures, it was found that BRZ5 gradation with 5% crushed stone dust filler samples provided higher stability than all other mixtures. Marshall test results of the mixture at various bitumen content with BRZ5 design gradation are shown in the figure 4.Thus, for this study, the mixture with BRZ5 gradation is selected as design aggregate gradation with 5% optimum filler content according to maximum Marshall stability which is 9.13 KN.

3.2.1 Comparison Marshall parameters at optimum bitumen content

From Table 7, Marshall parameters of three various gradations with varying filler content were tabulated at their corresponding optimum bitumen content. The stability of three mixtures produced from BRZ of Superpave gradation BRZ4, BRZ5, and BRZ6 was obtained to be 8.33KN, 9.13KN, and 7.76 KN, respectively. From this result, the maximum Marshall stability

Table 3. Properties of the 60/70 penetration grade bitumen.

Test	Test Method (ASTM)	Test result	Specification as per ERA
Penetration (25°C; 0.1 mm)	ASTM D 5	64	60–70
Ductility (25°C; cm)	ASTM D 113	79	Min. 50
Softening point (°C)	ASTM D 36	48	46–56
Specific gravity (25°C; g/cm^3)	ASTM D 70	1.024	-
Flash Point (°C)	ASTM D 92	298	Min. 232

Table 4. Average Marshall test data of mixture with BRZ4 gradation with CSD filler.

Bitumen Content, By Weight, %	ρA (g/cm3)	VIM(%)	VMA(%)	VFA(%)	Stability, KN	Flow, mm
4.0	2.226	8.4	16.8	49.7	7.71	2.08
4.5	2.260	6.5	15.9	59.3	8.04	2.84
5.0	2.279	5.5	15.7	64.6	8.56	3.36
5.5	2.319	3.2	14.6	78.2	8.27	3.53
6.0	2.323	2.6	15.0	82.8	7.43	3.69

Table 5. Average Marshall test data of mixture with BRZ5 gradation with CSD filler.

Bitumen Content, By Weight, %	ρA (g/cm3)	VIM(%)	VMA(%)	VFA(%)	Stability, KN	Flow, mm
4.0	2.250	7.8	15.8	50.6	8.08	2.38
4.5	2.274	6.3	15.4	59.3	8.91	2.52
5.0	2.315	3.8	14.3	73.4	9.21	2.96
5.5	2.318	2.9	14.7	80.0	8.69	3.34
6.0	2.306	2.9	15.7	81.3	8.00	3.41

Table 6. Average Marshall test data of mixture with BRZ6 gradation with CSD filler.

Bitumen Content, By Weight, %	Gsb (g/cm3)	VIM(%)	VMA(%)	VFA(%)	Stability, KN	Flow, mm
4.0	2.226	9.2	16.8	45.3	6.30	2.09
4.5	2.241	7.7	16.7	53.9	7.28	2.20
5.0	2.281	5.2	15.6	66.8	7.84	2.63
5.5	2.318	2.9	14.7	80.4	7.53	2.80
6.0	2.320	2.3	15.1	84.7	7.08	2.96

of 9.13 KN was found from mixtures with BRZ5 gradation with 5% filler content. stability than the other mixture. As shown in the Table 7, flow values of 3.52 mm, 2.93 mm, and 2.68 mm corresponding to optimum bitumen contents were obtained for BRZ4, BRZ5, and BRZ6 gradation, respectively. Flow values of three gradations indicate that as the gradation getting coarser, increasing flow value is observed. According to ERA 2002 pavement design manual, flow values of HMA, which are utilised in wearing courses, should be between 2 and 4 mm. Thus according to this test output, all gradation satisfied the minimum requirement. Among Marshall parameters, Air Void (VA) is another significant design mix factor. In ERA 2002 pavement manual specification, upper and lower limit values of air void are described. In the mixture with Superpave aggregate gradation with BRZ4, BRZ5, and BRZ6 gradation, an air void values of 4% were determined to correspond to OBC. According to ERA specification, on the surface wearing the course of the bituminous paving mixture, the value of the void is limited to 3%-5%. From the test results, the corresponding values of each filler proportion met the ERA specification.

The bulk-specific gravity of all mixtures produced from BRZ4, BRZ5, and BRZ6 gradation with a varying filler content of 4, 5, and 6% was found to be 2.302, 2.308, and 2.295 g/cm^3, respectively. The HMA mixture with BRZ5 with 5% filler content was relatively provided highest values of bulk density that is 2.308 g/cm3. Thus the mixture with BRZ5 Superpave gradation with 5% optimum filler content was selected as design gradation.

Void in mineral aggregate (VMA) is another significant Marshall parameter considerably affecting the mix properties. The percentage of VMA corresponding to optimum bitumen content was obtained to be 15.11, 14.57, 15.34% for the mixture with BRZ4, BRZ5, and BRZ6 Superpave gradation, respectively. The values of the test result of this study indicate that each gradation met the minimum requirements set by the ERA-2002. Another Marshall parameter is void filled with asphalt (VFA), which controls the quantity of bitumen filled micro voids. Values of VFA with respect to optimum bitumen content of mixtures with BRZ4, BRZ5, and BRZ6 Superpave gradation were obtained to be 72.75, 71.43 and 72.64%, respectively. As per Ethiopian road authority

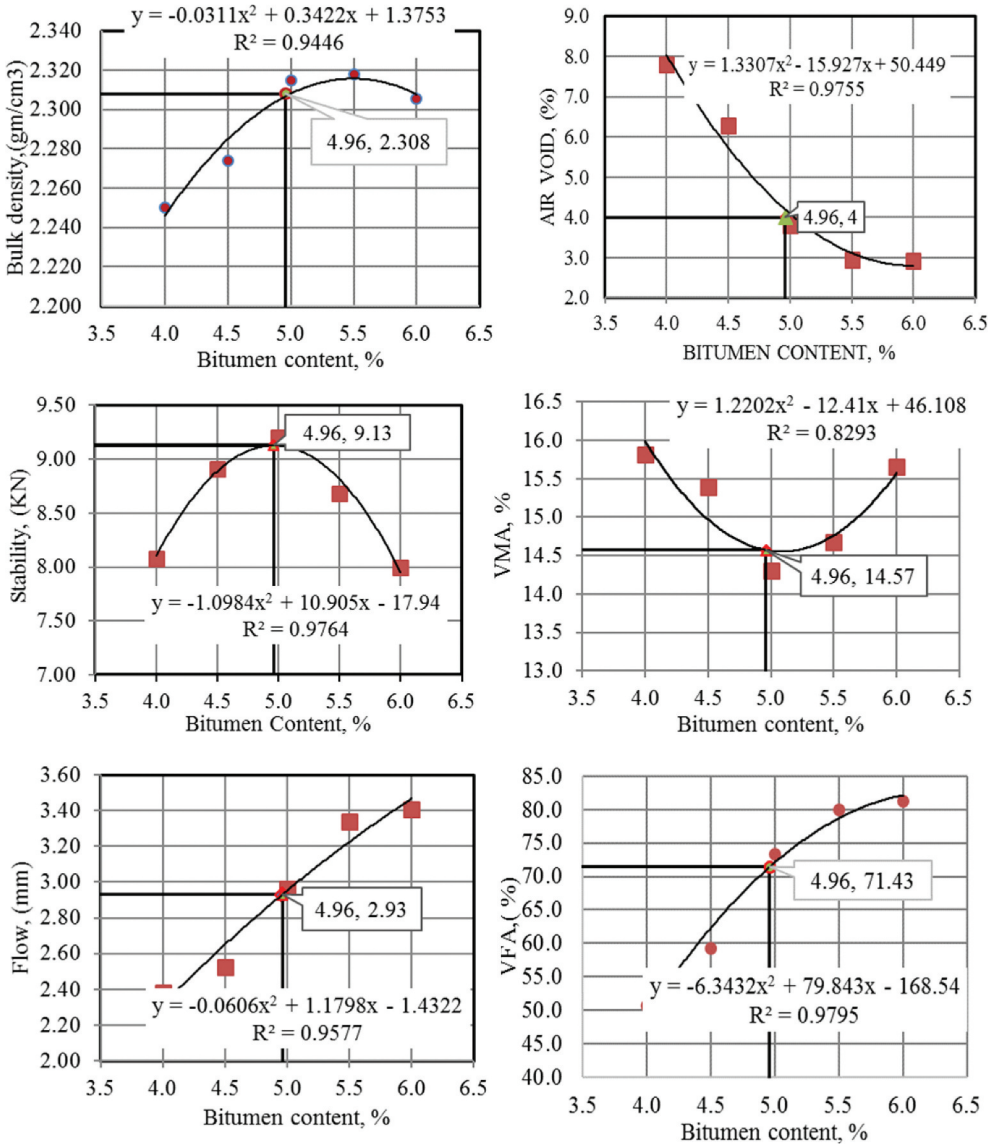

Figure 4. Marshall properties of HMA design data with BRZ5 gradation with OBC.

Table 7. Comparison Marshal properties of three gradations at OBC.

Gradation	OBC(%)	Stability(KN)	Flow(mm)	Bulk density(gm/cm3)	Va (%)	VMA(%)	VFA(%)
BRZ4	5.33	8.33	3.52	2.302	4	15.11	72.75
BRZ5	4.96	9.13	2.93	2.308	4	14.57	71.43
BRZ6	5.26	7.76	2.68	2.295	4	15.34	72.64
Specification requirements as per ERA, 2002	4–10	Min. 7	2–4	-	3–5	Min. 13	65–75

(ERA, Pavement Design Manual 2002) pavement design manual, in the wearing course, the maximum values of VFA should be 75%. The test results of this study indicate that BRZ4, BRZ5, and BRZ6 gradations are met with the specification requirement. Generally, from the test results, Superpave aggregate gradation with BRZ could be utilised in Marshall mix design without significant effect.

By comparing all the Marshall parameters of mixtures, it was found that BRZ5 gradation with 5% crushed stone dust filler samples provided higher stability than all other mixtures. Thus, for this study, the mixture with BRZ5 gradation is selected as design aggregate gradation with 5% optimum filler content according to maximum Marshall stability which is 9.13 KN.

3.3 Effects of various percentage of MWD filler combined with superpave gradation on Marshall properties of HMA

Based on the selected optimum bitumen content, and design gradation BRZ5 with 5% optimum filler content, and optimum bitumen content 4.96%, crushed stone dust filler was substituted partly and fully with marble waste dust filler with nine different proportion

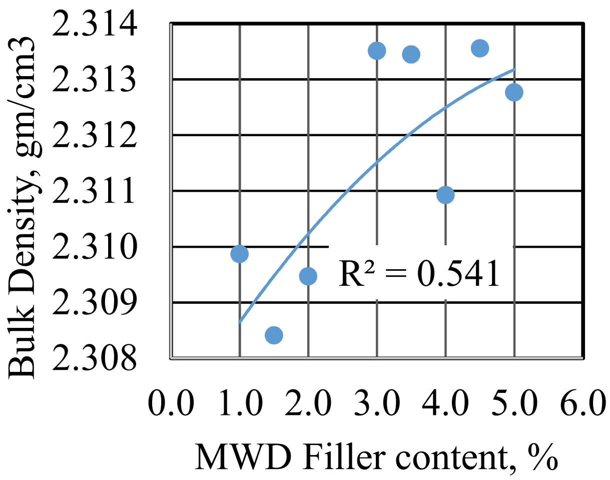

Figure 6. Relationship of MWD filler content and Bulk density of HMA mix.

at replacement rate of (1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, and 5%) by the mass of total filler content. The replacement of filler is done by keeping design gradation unchanged as well as bitumen (i.e. OBC 4.96%) content constant. Thus BRZ5 gradation is selected as control mix. Three samples each of them weighs 1,200 gm were fabricated for each filler proportion, and the average values of bulk specific gravity of mix, Marshall stability, flow, air void, void in mineral aggregate, void filled with asphalt were determined and compared with control mix as well as with specification.

3.3.1 Effects marble waste dust filler combined with Superpave aggregate gradation on Marshall stability

The relationship between stability and different percentage of marble waste dust filler when combined with Superpave gradation at OBC is shown in Figure 5 below. However, a good relationship exists between the two parameters (R2 = 0.7013).

Marshall stability of the mixture increase as marble waste dust filler proportion increase until it attains the maximum stability value of 10.18 KN at a replacement rate of 3% of marble waste dust filler. Afterwards, it begins to decrease. However, the declining trend was within the specification limit which suggest minimum stability of 7 KN as per ERA-2002. Hence, above stability values were fulfilled and accepted.

3.3.2 Effects marble waste dust filler combined with Superpave aggregate gradation on Bulk Density

From Figure 6, the bulk density of the replaced mixture fluctuates around the value of the control mix, which is 2.308 gm/cm3. However, the highest bulk density value was 2.314 gm/cm3 obtained from the mixture at 3% and 4.5% MWD filler content. The test results revealed that the partial replacement of CSD filler by MWD filler indicates a slight difference with respect to the unit weight of the mixture. This small variation is observed due to the reason that the unit weight of crushed stone and marble waste dust are in

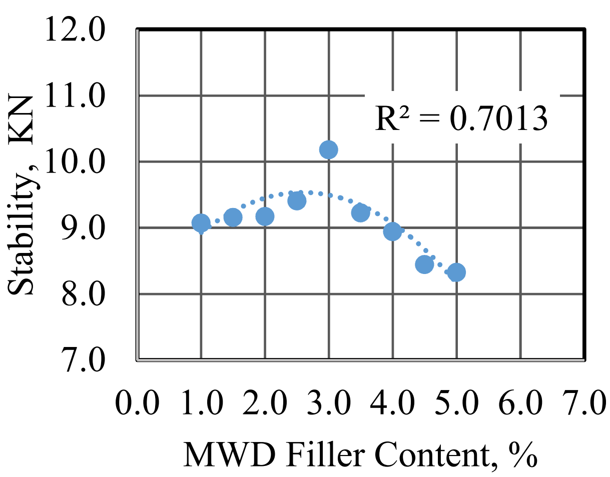

Figure 5. Relationship of MWD filler content and Marshall stability.

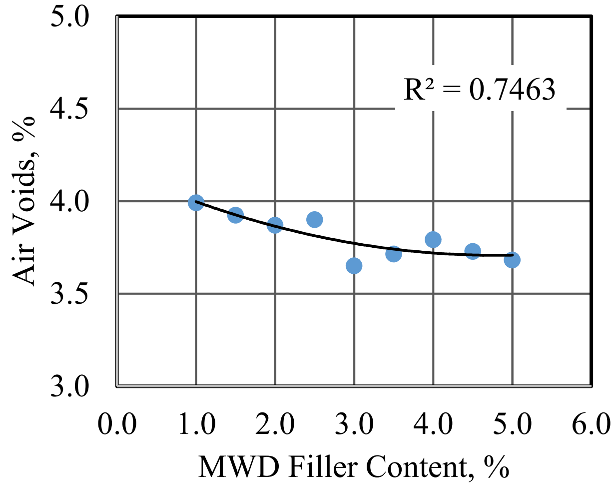

Figure 8. Relationship of MWD filler content and Air Void of HMA mix.

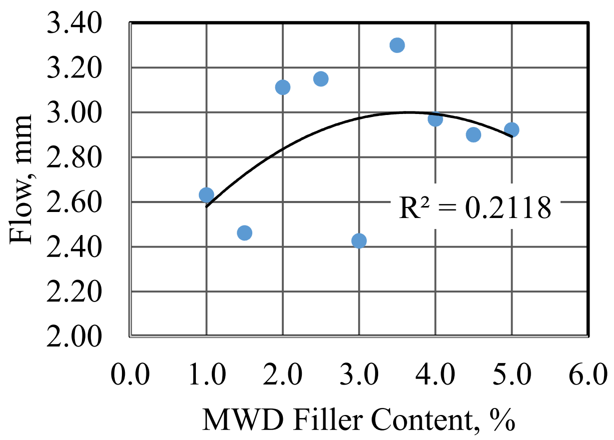

Figure 7. Relationship of MWD filler content and flow of HMA mix.

the same range which is 2.640 gm/cm3 and 2.697 gm/cm3, respectively. And also all mixtures are fabricated at the same bitumen content (OBC) without changing the design gradation.

3.3.3 Effects of Marble waste dust filler combined with Superpave aggregate gradation on Flow

The relationship between partial replacement of MWD filler and Marshall flow is provided in Figure 7. The test results indicated that there is a weak relationship between MWD filler content and Marshall flow. A positive regression coefficient (R2 = 0.1213) was obtained between flow and MWD filler which reveals poor correlation. The Marshall flow values of the HMA mixture, which is suggested by the [19] in asphalt binder wearing courses, should be within a range of 2 mm-4 mm. However, the flow value of all mixtures partially to fully replaced by MWD filler satisfied the requirement. However, the lowest value of flow was 2.43 mm, observed from the mixture corresponding to 3% marble waste dust filler.

3.3.4 Effects of Marble waste dust filler combined with Superpave aggregate gradation on Air void

Air Void (VA) is another significant design mix factor. It is well known that in pavement design manual specification, upper and lower limit values of air void are described within a range of 3% –5%. Various content of marble waste dust filler with Air voids results are presented in Figure 8. According to the test results, all HMA mixtures prepared with partially to fully replaced by marble waste dust filler provided the air void content within the range of 3%-5%. It is investigated that as the proportion of marble waste dust filler increases, the air void in the total mix decreases slightly. However, since all Marshall specimens produced at fixed OBC and with the same design gradation, the air void values of mixtures were not altered extremely.

3.3.5 Effects of Marble waste dust filler combined with Superpave aggregate gradation on VMA

Void in mineral aggregate (VMA) is another significant Marshall parameter considerably affecting the mix properties. From Figure 9, void in mineral aggregates results attain for all MWD filler contents. The result showed the HMA mixture containing 3%, 4.5%, and 5% MWD filler exhibit the lower percentage of VMA found as 14.3%. This indicates that the absorbance of bitumen could be decreased due to a low level of porosity on the surface of the MWD particle together with coarser aggregate.

3.3.6. Effects of Marble waste dust filler combined with Superpave aggregate gradation on VFA

The relationship between marble waste dust filler proportion and the void filled with asphalt (VFA) is indicated in Figure 10. As shown from Figure 10, VFA values increase with an increase replacement rate of marble waste dust filler until it reaches the highest VFA value at 3% marble waste dust. The void filled with asphalt values for 3% MWD filler is found to be 74.5%. According to ERA pavement design, manual VFA values in hot mix asphalt mixtures are within a range of 65–75%. Thus, as can be seen from Figure 10, all mixture with marble waste dust combined with Superpave gradation are satisfied the requirement.

3.4. Determination of best replacement rate of Marble Waste Dust filler content

In order to find the best replacement filler content that produces an HMA mixture with the best marshal properties, a combination of mechanisms and control are suggested (Jendi. et al. 2013). Asphalt mixture with an optimum filler content satisfies the following conditions: Maximum stability, Maximum bulk density, and Va % are within the allowed range of specifications. As it is noticed from Table 8, stability values of all HMA mixture for various marble waste dust filler content met local and international specifications, which are 7KN and 8.006KN, respectively. But, the maximum stability value was obtained from the mixture corresponding to 3% MWD filler relative to other proportions. Also corresponding to this proportion, air void, and bulk density values are obtained to be 3.7% and 2.314 gm/cm3, respectively, which are satisfactory.

Thus, the HMA mixture prepared with partial replacement of MWD filler at (3% MWD+2%CSD) blended with BRZ of Superpave gradation satisfies the requirement of both local and international specification limits for all tested Marshall parameters.

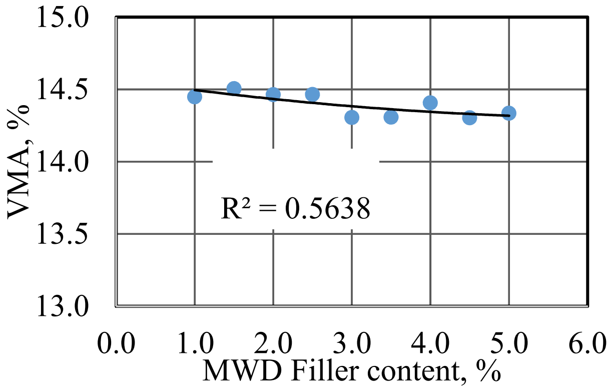

Figure 9. Relationship of MWD filler content and void in mineral aggregate.

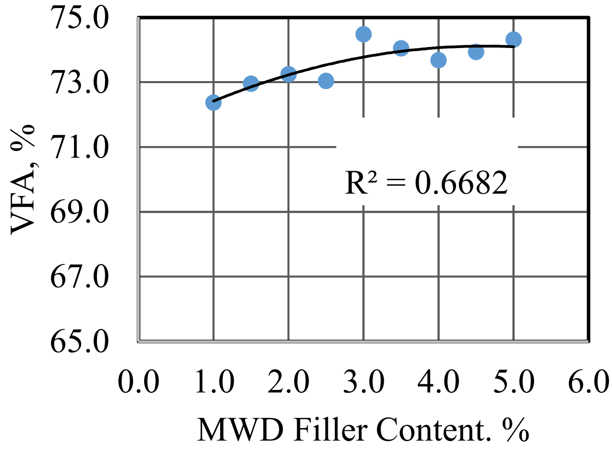

Figure 10. Relationship between VFA and replacement rate of MWD fillers

Table 8. Summary of Marshall parameters of HMA mixture at varying MWD filler content.

MWD Content, By Weight of Total Mix, %	Gsb (gm/cm3)	VA, (%)	VMA,(%)	VFA, (%)	Stability, (KN)	Flow, (mm)
1.0	2.310	4.0	14.4	72.4	9.07	2.63
1.5	2.308	3.9	14.5	72.9	9.15	2.46
2.0	2.309	3.9	14.5	73.2	9.17	3.11
2.5	2.309	3.9	14.5	73.0	9.40	3.15
3.0	2.314	3.7	14.3	74.5	10.18	2.43
3.5	2.313	3.7	14.3	74.0	9.22	3.30
4.0	2.311	3.8	14.4	73.7	8.94	2.97
4.5	2.314	3.7	14.3	73.9	8.44	2.90
5.0	2.313	3.7	14.3	74.3	8.32	2.92

Hence, for this study 3%, MWD content is selected to be the best filler replacement proportion based on maximum Marshall stability.

3.5. *Comparison of properties of asphalt mix at optimum MWD with local and international specifications*

The comparison of Marshall and volumetric properties of asphalt mixture at optimum marble waste dust indicated the content of 3% MWD by weight of the optimum-crushed stone dust filler with local and international specifications. Table 9 shows the asphalt mixture with best replacement content of marble waste dust filler at 2% CSD plus 3% MWD by mass of total constituent of aggregates satisfied the requirements of Ethiopian Road Authority Pavement Design Manual (ERA, PDM) 2002, and the Asphalt Institute Specifications for all tested parameters. Hence, the use of marble waste dust filler at 3% by mass of crushed stone dust filler when combined with a below restricted zone of Superpave gradation is acceptable.

4. Conclusions and recommendations

The substantial effects of marble waste dust filler when combined with Superpave aggregate gradation on the hot mix asphalt was studied through a sequence of experimental laboratory tests. From the analysed results of test data, the following conclusion and recommendations could be forwarded. Below restricted zone of Superpave aggregate gradation, which near to the lower limit of local gradation specification, can be used in Marshall mix design within local specifications.

The use of both partial and full replacement of Marble waste dust filler at various proportions blended with below-restricted zone (BRZ) Superpave gradation fulfilled the requirement for HMA mixture set in ERA PDM 2002.

Partial replacement of crushed stone filler by marble waste dust when combined with Superpave gradation (BRZ) showed a significant effect on the HMA mixture stability at the replacement rate of 3% MWD. At 3% MWD, the HMA mixture provided the highest stability 10.18 KN, highest bulk density, and all other mix design parameters were within allowable limits.

Generally various characteristics of hot mix asphalt were investigated when the marble waste dust filler combined with Superpave aggregate gradation. This shows that filler and aggregate gradation are substantial ingredient influencing the HMA mixture properties.

Finally, by taking into account the effects of industrial waste, it is recommended to recognise the usage of marble waste dust filler as an alternative filler in asphalt pavement construction which sequentially have an advantage in reducing environmental pollution.

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Disclosure statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Table 9. Comparison of the properties of asphalt mix with best replacement rate of MWD filler.

Marshall parameters	MWD filler content (OMWD = 3%)	Local specification (ERA, 2002) Min.	Local specification (ERA, 2002) Max.	International specification (Asphalt Institute, 1996) Min.	International specification (Asphalt Institute, 1996) Max.	Remark
Stability (KN)	10.18	7	-	8.006	-	Ok
Flow, (mm)	2.43	2	4	2	3.5	Ok
Bulk Density, (gm/cm^3)	2.314	-	-	-	-	Ok
Percentage of air voids in total mix (Va %)	3.7	3	5	3	5	Ok
VMA	14.3	13	-	13	-	Ok
VFA	74.5	65	75	65	75	Ok

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