

Effect of Partial Replacement of Crushed Stone Dust Filler with Waste Glass Powder in Hot Mix Asphalt Concrete Production

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Abstract— The use of waste recycled materials in road construction nowadays is considered a positive means of providing improved pavement performance. This research focused on evaluating the effect of waste glass powder as a partial replacement of crushed stone dust filler in hot mix asphalt. Three hot mix asphalt samples were produced using crushed stone dust of 5%, 6.5%, and 8% as mineral filler with five different bitumen content of 4%, 4.5%, 5%, 5.5%, and 6%, respectively. From the preliminary series tests of asphalt contents, a 6.5% crushed stone dust filler selected, providing the highest waste glass powder stability. The content of crushed stone dust filler was replaced with a rate of 0%, 25%, 50%, 75%, and 100% to test Marshall stability to obtain the Optimum bitumen content and Optimum filler content. Results indicated at 75% replacement of crushed stone dust with waste glass powder at 5.10% bitumen content, 12.0kN Marshall stability value, 2.84mm Flow value, 4.0% Air voids, 72.3% VFB, and 2.360g/cm³ Bulk density. Hence, the mixture of 75% waste glass powder by weight of crushed stone dust filler meets the minimum requirements of the Ethiopian Road Authority and Asphalt Institute Specifications.

Keywords— Crushed stone dust, Hot Mix Asphalt, Marshall stability, Optimum filler content, Waste glass powder.

I. INTRODUCTION

One of the alarming threats to the environment is the accumulation of waste materials such as rubber, glass, metal, plastic, etc. As the population increases, the volume of waste is rapidly increasing, and waste disposal has to be increased proportionally [1].

The disposal of that large quantity of wastes, especially non-decaying waste materials, becomes a problematic issue in developed and developing countries worldwide [2], [3]. Suppose many waste or by-product materials are generated instead of natural materials in construction projects. In that case, three benefits can be derived: conservation of natural resources, disposing of waste materials (which are often unsightly) and freeing up valuable land for other uses [3], [4], [5]. Local government bodies are struggling with the capacity of municipal solid waste. Recycling is one of the most suitable and economical ways of disposing of solid waste materials. With ever-decreasing material supply and increasing prices, there has been a renewed interest in reusing the waste materials in many fields of construction [4], [5].

Waste material recycling into useful products has become the primary solution to waste disposal problems. So, research into new and innovative uses of waste materials is extensively encouraged. Many highway agencies are conducting various studies and research projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. These studies tried to find an adequate combination of the need for safe and economical disposal of waste materials and the need for satisfactory and cost-effective pavement materials. Recycled materials used in road construction nowadays provided a positive option considering sustainability sources of materials and as an attractive materials option to provide satisfactory performance in service [5].

There were considerable numbers of literature published on the reuse of solid waste considered raw ingredients in Hot Mix Asphalt Concrete (HMAC) [6]. Generally, there are three ways to announce waste material into HMAC. One advent is to introduce the waste material used as a modifier to the asphalt binder. Studies indicated that when an asphalt binder is modified with rubber, polymer, and many other waste materials, HMAC exhibits better properties [6], [7]. The second advancement is solid waste material use as a replacement of conventional fillers and aggregates in HMAC. Conclusions from several studies confessed the importance of the filler used in asphalt concrete [8], [10].

Further, it is accepted worldwide that the natural filler can be replaced with any suitable material, either natural or artificial. The third method used additives such as polymers and fibers to HMAC in addition to the binders and aggregates. The performance of Hot mix asphalt with PET and HDP in stone mastic asphalt was tested in many studies [10], [11]. The mechanical properties of asphalt concrete depend on the properties of fillers and bitumen. Modifications of asphalt paving materials with high-quality additives are quite costly for the production of bituminous road construction mixtures. To reduce this problem's impact is by considering the application of natural mixture ingredients [12], [13].

One of the major concerns in the mix designing is the type and amount of filler used, which is known to highly affecting the mix design, especially the optimum asphalt content. The amount of filler used in the plant mixes will be a factor in affecting the properties of the mix produced [14]. In some studies, it revealed that the replacement or addition makes the mix better. Some conventional construction materials like lime, cement, and granite powder are commonly used as fillers in asphalt concrete mixture worldwide. Cement, lime, and granite powder are expensive and used for other purposes more effectively [15], [16].

In this study, the effect of waste glass powder using partial replacement of conventionally used filler material such as crushed stone dust in hot mix asphalt concrete was evaluated. The laboratory experiment performed on samples at different percentages of the primary conventionally used crushed stone dust filler by replacing with a waste glass powder to determine the Marshall Stability, flow, and volumetric properties by the Marshall mix design method.

II. MATERIALS AND RESEARCH METHODOLOGY

A. Materials

The materials used for this study are crushed stone as coarse and fine aggregate and 85/100 Penetration grade of bitumen as binder material. Crushed stone dust filler and aggregates were obtained from IFH Engineering PLC Construction Quarry site around Kaliti area four different sizes: 14-25mm, 6-14mm, 3-6mm, and 0-3mm. The asphalt cement of 85/100 Penetration grade also obtained from IFH engineers PLC batching plant. Waste glass bottle was collected from Addis Ababa Glass and Bottles Shear Company's waste bottles stockpile. Specimens of the waste glass bottles such as white, amber, and green bottles were collected.

B. Tests on Materials

The experiment based on laboratory testing of materials as the main approach to achieve research goals. All the testing conducted using equipment and devices available in the laboratory of IFH Engineering PLC. Laboratory tests are divided into several steps, which started with an evaluation of the properties of used materials such as mineral filler (i.e., crushed stone dust and waste glass powder), mineral aggregates, and bitumen. Aggregate quality test performed, including the Los Angeles Abrasion test, sand equivalent, flat and elongated particles.

1) *Physical Properties Mineral Filler*: Mineral fillers contain finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, loess, and other suitable mineral materials. Aggregate passing 0.075 mm sieve, will serve as filler materials. The filler fills the voids, stiffens the binder, and offers permeability [17, 18]. The fillers used in this study, namely crushed stone dust and waste glass powder. Laboratory tests were performed to evaluate each type of filler's physical properties, which consisted of the gradation parameters, Plasticity Index, and Apparent Specific gravity. Table I shows all types of fillers passing the sieve No.30, No.50, and No.200 that conformed with the range specified by ASTM D242. Both crushed stone dust and waste glass powder are Non-plastic (NP), with the apparent specific gravity of crushed stone dust of 2.725, while the waste glass powder of 2.653. The apparent specific gravity of the waste glass powder sample is slightly lower than the crushed stone dust.

TABLE I
PHYSICAL PROPERTIES OF USED MINERAL FILLER

Sieve No.	% Passing		ASTM D242
	Waste Glass Powder	Crushed Stone Dust	
No. 30	100	100	100
No. 50	100	100	95-100
No. 200	100	100	70-100
Plasticity Index	NP	NP	< 4
Apparent specific gravity	2.653	2.725	--

2) *Mineral Aggregate Tests and preparation*: Aggregates (mineral aggregates) are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Aggregate gradation, shape, surface texture, water absorption, resistance to crushing, and impact loads significantly impact a shear strength hot mix asphalt property. AASHTO, ASTM, and BS standards are taken to test the methods of road construction for dense graded asphalt. The mineral aggregates used in the research were subjected to various tests in order to determine their physical characteristics and suitability for use the road construction; various tests were conducted, and the results are presented in Table II.

TABLE II
PHYSICAL PROPERTIES AGGREGATE

Test	Test Method	Test Result				ERA Specification
		14-25mm	6-14mm	3-6mm	0-3mm	
Bulk dry S. G	AASHTO T 85-91	2.626	2.618	2.610	2.610	--
Bulk SSD S. G		2.675	2.667	2.661	2.667	--
Apparent S. G		2.761	2.753	2.749	2.767	--
Water absorption, %	BS 812, Part 2	1.9	1.9	1.9	--	<2
Sand Equivalent, %	AASHTO T176-86	76.8	--	--	--	>40
Flakiness Index	BS 812 Part 105	22	--	--	--	<45
ACV, %	BS:812 Part 110	12	--	--	--	<25

LAA, %	AASHTO T 96	13	--	--	--	<30
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3) *Combined Gradation of Mineral Aggregates*: Asphalt mix requires the blending of two or more aggregates, having different gradations, to produce an aggregate blend that meets the gradation specifications for asphalt mix. Available aggregate materials, coarse aggregate (14-20mm), intermediate aggregate (6-14mm and 3- 6mm), fine aggregate (0- 3mm) and filler, were integrated in order to get the proper gradation within the allowable limits according to ASTM specifications using the mathematical trial method. The summary of combined gradation of aggregates and the specification criteria for asphalt binder coarse is given in figures 1, 2 & 3 for the three types of gradations based on three varying percentages of filler 5.0%, 6.5%, and 8.0% with 19mm maximum aggregate size designed from percent passing.

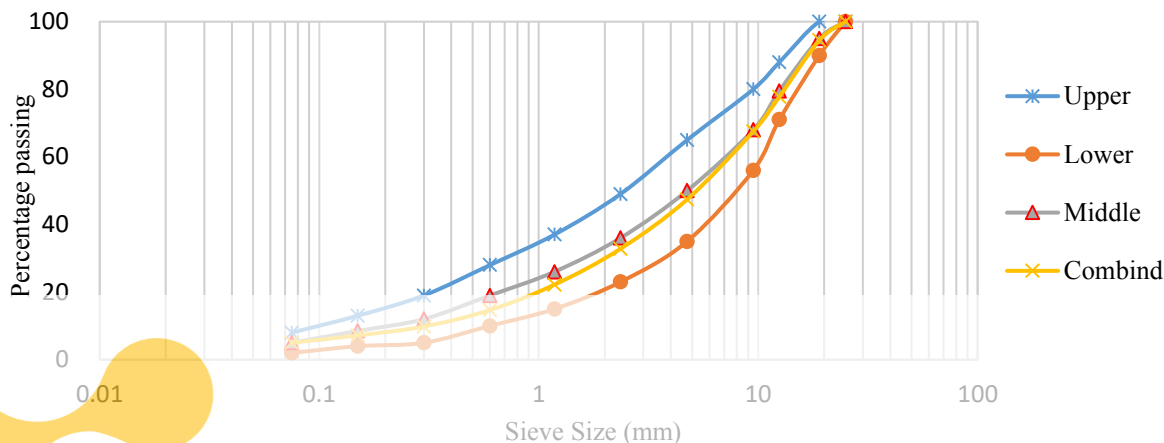


Fig. 1 Combined aggregate gradation for 5% Mix

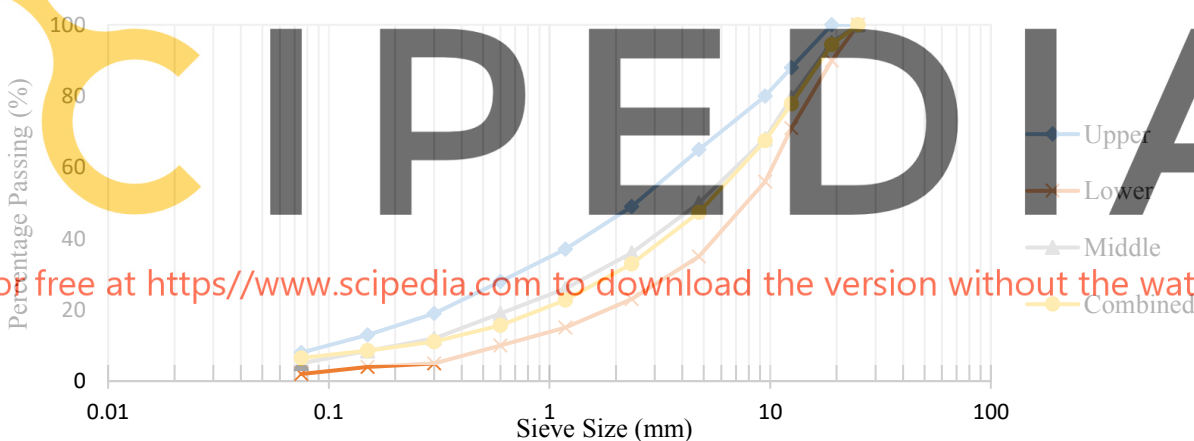


Fig. 2 Combined aggregate gradation for 6.5% Mix

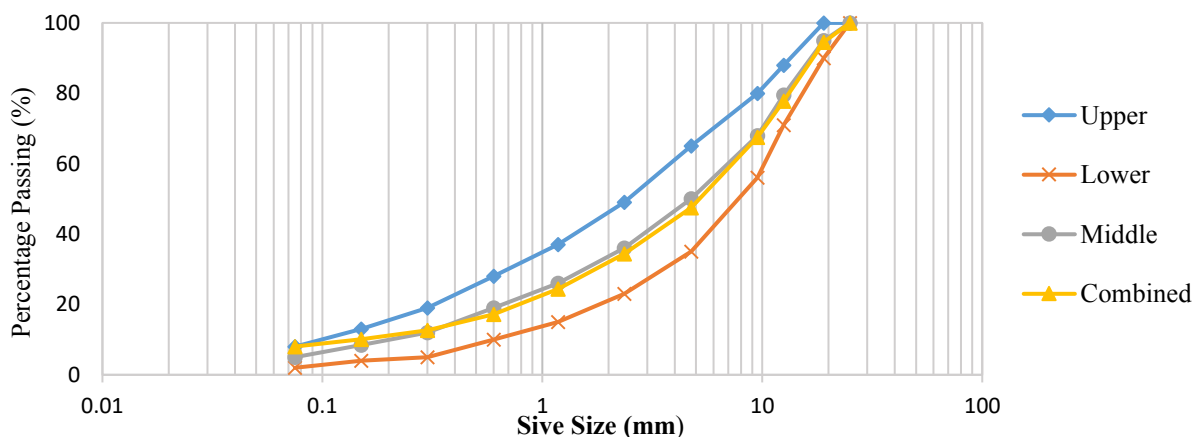


Fig. 3 Combined aggregate gradation for 8% Mix

4) *Asphalt Binder Selection and Test*: Bitumen acts as a binding material to the coarse and fine aggregates and stabilizers in bituminous mixtures. Binder provides durability to the mix. The asphalt binder was used in this study with a penetration grade of 85/100. The physical properties of the asphalt binder are determined according to the procedure specified by AASHTO

standards. A series of tests performed, including penetration, specific gravity, softening point, ductility, and solubility in carbon tetrachloride for penetration grade asphalt's basic characterization properties. The test requirement of ERA specifications and table III presented the summary of the 85/100 penetration grade binder's various properties.

TABLE III
PROPERTIES OF THE 85/100 PENETRATION GRADE BITUMEN

Properties	Unit	Test Method (AASHTO)	Test Results	Recommended (ERA Specification for 85/100)
Penetration (25°C, 100gm, 5.0sec)	(0.1mm)	T 49	90.7	85-100
Softening point	(°C)	T 53	48.8	42-51
Ductility(25°C)	(cm)	T 51	105	>100
Solubility	(%)	T 44	99.74	>99%
Specific gravity at (25°C)	(g/cm ³)	T 228	1.017	-

III.RESULTS AND DISCUSSION

A. Marshall Test Results and Discussion

The Marshall properties of specimens prepared with varying content 5.0%, 6.5%, and 8.0% of crushed stone dust as filler by weight of aggregate together with varying bitumen contents. A total of 45 samples, each of them weighs 1200 grams, were prepared using five different bitumen contents of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0% of total weight Optimum filler and the bitumen content at each three-filler content. Table IV-VI indicates mixtures' properties at their various bitumen content for mixes with different percentage of crushed stone dust filler content. Marshall design criteria for heavy traffic, minimum Stability must be 7.0 kN at 60°C, flow value must be ranged between 2mm to 4mm, percentage of Air voids must be ranged between 3%-5%, a minimum VMA related to 4% air voids, the nominal maximum particle size of 19mm must be 13, and VFB must be ranged between 65% to 75% [19].

TABLE IV
AVERAGE VOLUMETRIC PROPERTIES OF THE ASPHALT CONCRETE WITH 5.0% CSD FILLER

Bitumen Content by weight (%)	ρ_A (g/cm ³)	VIM (%)	VMA (%)	VFA (%)	Stability (kN)	Flow (mm)
4.0	2.320	6.5	14.9	56.0	7.9	2.73
4.5	2.348	4.7	14.3	67.0	8.6	3.08
5.0	2.354	3.8	14.5	74.1	8.7	3.38
5.5	2.359	2.8	14.8	80.8	9.0	3.75
6.0	2.351	2.5	15.5	84.1	7.9	4.12

TABLE V
AVERAGE VOLUMETRIC PROPERTIES OF THE ASPHALT CONCRETE WITH 6.5% CSD FILLER

Bitumen Content by weight (%)	ρ_A (g/cm ³)	VIM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	2.311	7.5	15.2	50.8	8.2	3.02
4.5	2.328	6.1	15.0	59.4	10.6	2.64
5.0	2.356	4.2	14.4	70.8	11.1	3.31
5.5	2.373	2.8	14.3	80.5	9.9	3.37
6.0	2.377	2.1	14.6	85.3	9.6	3.44

TABLE VI
AVERAGE VOLUMETRIC PROPERTIES OF THE ASPHALT CONCRETE WITH 8.0% CSD FILLER

Bitumen Content by weight (%)	ρ_A (g/cm ³)	VIM (%)	VMA (%)	VFA (%)	Stability (kN)	Flow (mm)
4.0	2.301	8.0	15.6	48.9	7.9	2.12
4.5	2.326	6.3	15.1	58.6	8.6	2.92
5.0	2.343	4.9	14.9	67.5	9.9	2.58
5.5	2.355	3.7	14.9	75.6	9.7	2.73
6.0	2.363	2.6	15.1	82.8	9.4	2.56

B. Determining Optimum Bitumen Content

The Marshall test was used to examine the specimens of asphalt mixture with different bitumen content percentages, which were 4.0%, 4.5%, 5.0%, 5.5%, and 6.0%, to obtain the optimum bitumen content. The optimum bitumen content is determined by the National Asphalt Pavement Association (NAPA) method in which they suggested by preparing plots, as shown in figure 4. The optimum bitumen content is calculated first by finding the bitumen content, which corresponds to median air void content, at 4% of the ERA Specification. That bitumen content is then used to determine the values for Marshall stability, Flow, VMA, VFA, and percent of Voids filled from each of the plots in figure 4. Each value is compared against the specified value for that property, and if all values are within the specified range, the bitumen content at 4 percent Air voids is the Optimum bitumen content [20]. Based on the laboratory result, the optimum bitumen content is 5.10%, at 4% Air voids with a corresponding 6.5% of Crushed stone dust (CSD) filler.

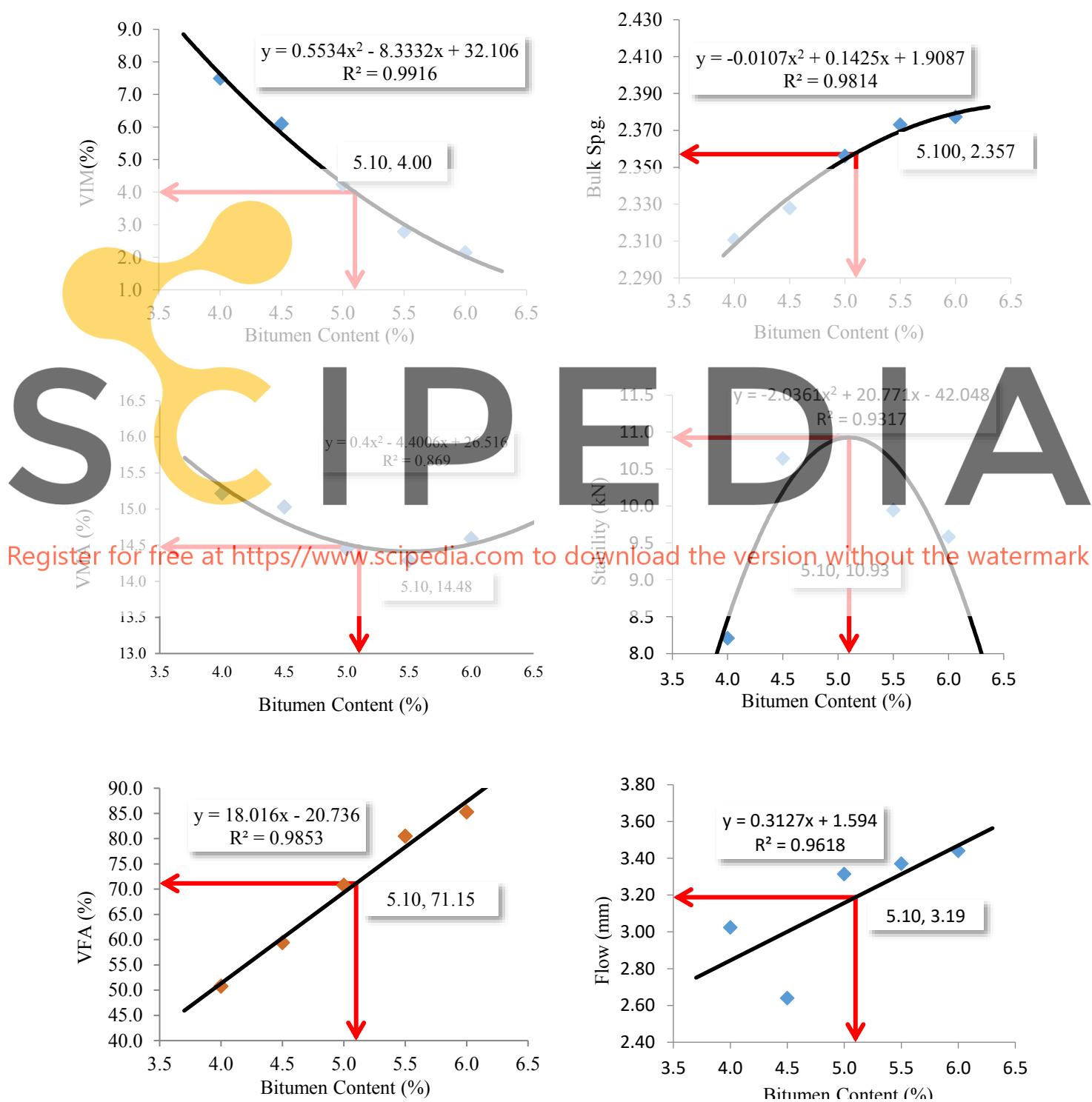


Fig. 4 Optimum bitumen content (OBC) and the properties of mixtures with 6.5% CSD filler

1) Comparison of OBC at percentage *mix proportion of Crushed Stone Dust (CSD) filler*: Table VII illustrates the mixes' Marshall properties corresponding to three varying filler content. The Optimum Bitumen Content (OBC) of 5.0 %, 6.5% and 8.0% CSD filler indicated 4.84%, 5.10% and 5.34%, respectively. The Marshall stability values of mixes containing 5.0 %, 6.5%, and 8.0% CSD filler were 8.84, 10.93, and 9.79kN, respectively, in which all the results are within the specification. The flow values of all the mixes respective to OBC stayed in the specified range of 2-4mm. It was observed that asphalt mixes with all three-filler content produce a satisfactory result, as suggested in the ERA Pavement design manual. As a result of the experimental study, 6.5% crushed stone dust samples provided higher Stability than the other mixture. Hence, the optimum bitumen content requirement in the case of 6.5% crushed stone dust filler is almost the same as for 5.0% crushed stone dust and less bitumen than 8.0% crushed stone dust mixtures. All the mixtures compared; it was found out that 6.5% crushed stone dust samples showed higher Stability than all other mixtures. So, the result of 6.5% crushed stone dust was considered Optimum filler content based on the maximum Marshall stability test result. On the other hand, a 6.5% crushed stone dust was selected for a replacement filler material for further tests considering its Stability, OBC, and Flow that are obtained satisfactorily of the established criteria. In this study, the replacement of the mixture for laboratory tests was considered a 5.10% OBC and optimum filler content of 6.5% filler content.

TABLE VII
COMPARISON OF OBC AND MARSHAL PROPERTIES AT THREE PERCENTAGE OF MIX PROPORTION

Properties	Crushed Stone Dust (CSD) Filler content by weight			(ERA, Pavement Design Manual)
	5.0%	6.5%	8.0%	
Bitumen, %	4.84	5.10	5.34	4-10%
Air void, %	4.00	4.00	4.00	3-5%
VMA, %	14.38	14.48	14.90	Min. 13%
VFA, %	70.09	71.15	72.43	65-75%
Stability, kN	8.84	10.93	9.79	Min. 7kN
Flow, mm	3.30	3.19	2.63	2-4mm

C. Relationship of Marshall Properties with Waste Glass Powder Filler Material

The effects of replacing various proportions of the primary used filler with the Waste Glass Powder (WGP) filler on Marshall stability, flow, and volumetric properties of a typical binder course asphalt concrete are evaluated. On the basis of determining the amount of optimum bitumen content of 5.10% and optimum content of 6.5%, crushed stone dust filler replaced at four incremental 25, 50, 75, and 100% by weight of CSD filler with WGP filler as shown in table VIII. Hot mix asphalt mix with no waste glass powder filler served as the control mixture for the subsequent laboratory tests. The obtained asphalt concrete mix samples with the waste glass powder denoted by using WGPAC abbreviation, formed by the initials of "Waste Glass Powder Asphalt Concrete." The samples were numbered from WGPAC 1 to WGPAC 4 based on percentage value, starting from 25% to 100%.

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TABLE VIII
MIX PROPORTION OF ASPHALT CONCRETE MIXTURES USING DIFFERENT FILLER CONTENTS AND THEIR PROPORTIONS USED AGGREGATE

Sample Name	Coarse aggregate size	Intermediate aggregate size		Fine aggregate size	% of Crushed Stone Dust by weight	% of Waste Glass Powder by weight
	14-20mm	6-14mm	3-6mm	0-3mm		
Control Sample	5.5	27.0	20.1	40.9	6.5 (100%)	0 (0%)
WGPAC 1	5.5	27.0	20.1	40.9	4.875 (75%)	1.625 (25%)
WGPAC 2	5.5	27.0	20.1	40.9	3.25 (50%)	3.25 (50%)
WGPAC 3	5.5	27.0	20.1	40.9	1.625 (25%)	4.875 (75%)
WGPAC 4	5.5	27.0	20.1	40.9	0 (0%)	6.5(100%)

Marshall properties of asphalt mixes with Waste glass powder (WGP) at constant bitumen content of 5.10% are summarized in table IX. A total of 15 Marshall specimen of mixtures, each of them weighs 1,200gms prepared using five glass powder content of 0%, 25%, 5%, 75%, and 100% by weight of Crushed stone dust filler, and 5.10% Bitumen content by the weight of the total mix.

TABLE IX

AVERAGE MARSHALL PROPERTIES OF ASPHALT MIXES WITH WGP AT 5.10% OBC

Replacement (in %)	Content CSD & WGP filler	ρ_A (g/cm ³)	VIM (%)	VMA (%)	VFA (%)	Stability (kN)	Flow (mm)
0	6.5%CSD & 0%WGP	2.350	4.2	14.8	71.3	10.1	3.26
25	4.875%CSD & 1.625%WGP	2.352	4.3	14.7	70.8	10.4	2.96
50	3.25%CSD & 3.25%WGP	2.356	4.1	14.6	71.8	11.0	3.12
75	1.625%CSD & 4.875%WGP	2.360	4.0	14.4	72.3	12.0	2.84
100	0%CSD & 6.5%WGP	2.355	4.2	14.6	71.1	10.3	3.10

1) *Marshall Stability – Glass Powder Content Relationship*: Figures 5 showed that all Stability values with the replacement of WGP filler content had achieved the specification requirements. The figure indicated that the mixtures' Marshall stability value increased as the glass powder content increases until it reaches the maximum Stability of 12.0kN at 75% glass powder content. Beyond this point, it started to decline.

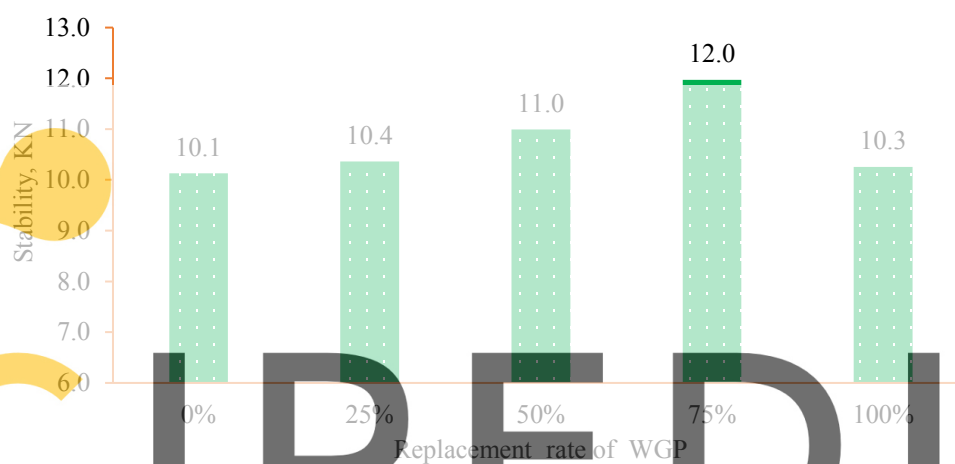


Fig. 5 Relationship between Stability and replacement rate of WGP fillers at constant bitumen content of 5.10%.

2) *Flow – Glass Powder Content Relationship*: The Flow value limit must be minimum at 2 mm, and a maximum at 4 mm for heavy traffic [17]. The flow of replacing mixes oscillates around the value of the control mix, which was 3.26 mm. It means the value was in the range of FRB Pavement Design Manual specifications at all replacement rates. When considering flow, the lowest flow value was obtained at the point of 2.84 mm for samples prepared and tested with 75% of WGP (i.e., 1.625% CSD filler and 4.875% WGP), a maximum flow value which was 3.26 mm for the sample prepared with 0% of WGP (i.e., 6.5% CSD and 0% WGP).

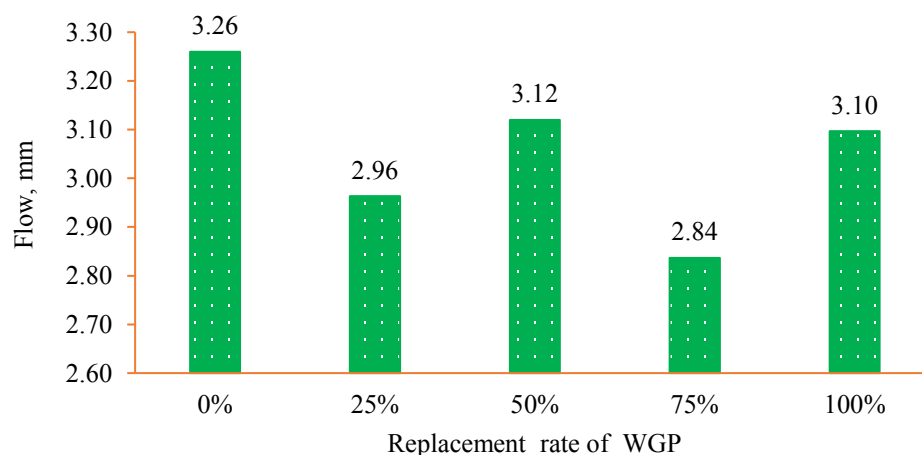


Fig. 6 Relationship between flow and replacement rate of WGP fillers at constant bitumen content of 5.10%.

3) *Bulk Density – Glass Powder Content Relationship*: Figure 7 shows that the bulk density increases with an increase in waste glass powder content until it reaches the maximum bulk density at 75% glass powder content, and it started to decline. So, the maximum bulk density determined value of 2.360 g/cm³ at 75% glass powder content, and the minimum bulk density of 2.350 g/cm³ at 0% glass powder content.

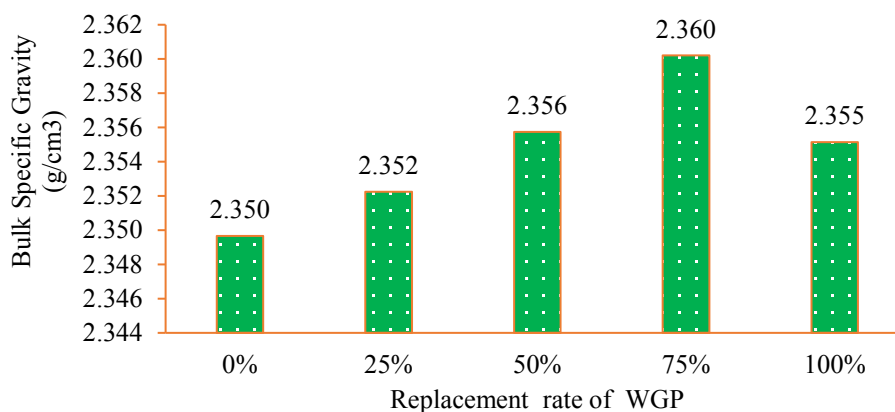


Fig. 7 Relationship between bulk density and replacement rate of WGP fillers at constant bitumen content of 5.10%.

4) *Air voids (Va) – Glass Powder Content Relationship:* It must be emphasized that the design range of air voids from 3%-5% was the desired level after several years of traffic. The mixes that ultimately consolidate to less than 3% can be expected to show signs of rutting and shoving; a similar problem like brittleness and premature cracking can occur if the final air void content is above 5% [18]. It was noticed that the Air void content for the replaced mixes from 0% - 100% glass powder filler, all values within the range of 3% - 5% as specified by ERA Standard, Pavement Design Manual. On the other hand, from figure 8 indicated at 75% glass powder content (i.e., the sample prepared by 1.625% CSD and 4.875% WGP, the air voids percentage was 4%, which was seen as the median value of local and international specifications.

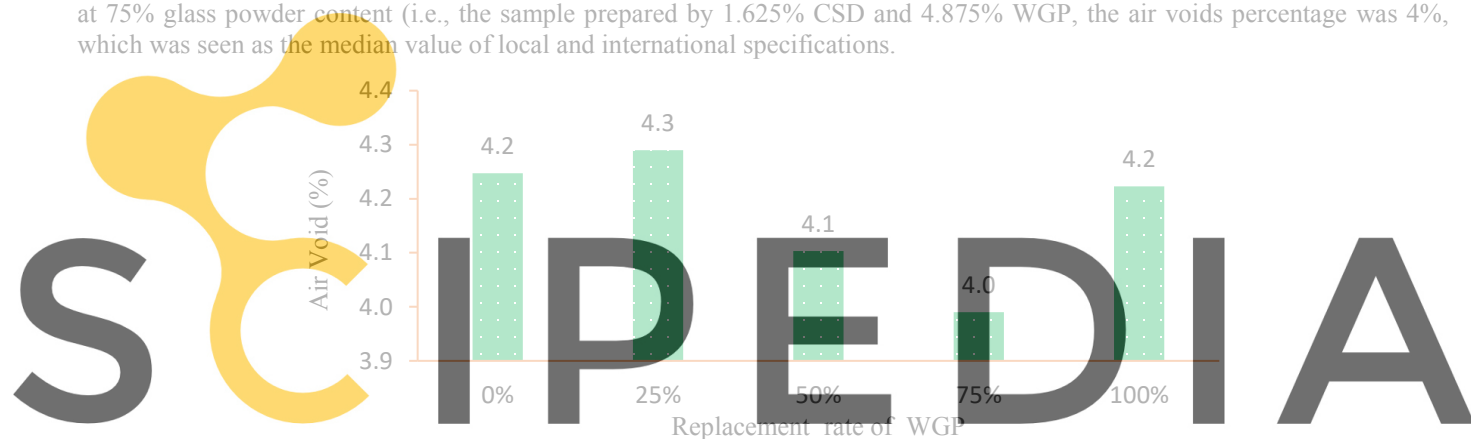


Fig. 8 Relationship between Air voids and replacement rate of WGP fillers at constant bitumen content of 5.10%.

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5) *Voids in Mineral Aggregates (VMA) – Glass Powder Content Relationship:* The relationship between glass powder content and voids in mineral aggregates is shown in figure 9. It is noticed that the voids in mineral aggregates decrease with increased glass powder content up to a minimum value; it increases at higher content of glass powder. The minimum VMA value is 14.4% of asphalt samples that were prepared with 1.625% CSD and 4.875% WGP. The voids in mineral aggregates value are all within the permissible limits specified in the ERA Pavement Design Manual.

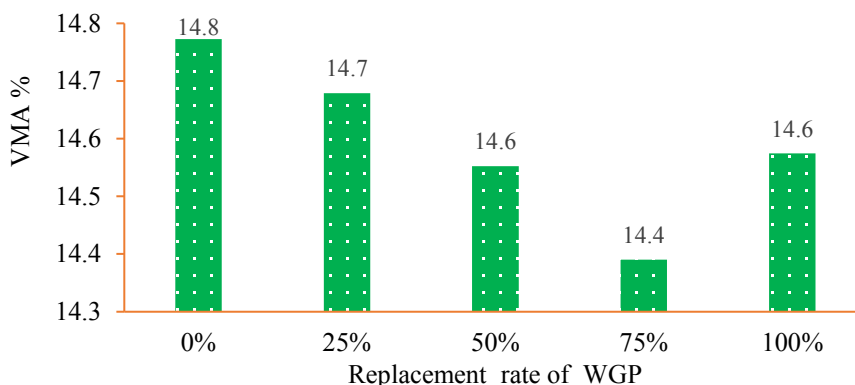


Fig. 9 Relationship between VMA and replacement rate of WGP fillers at constant bitumen content of 5.10%.

6) *Percent Voids filled with Asphalt (VFA)–Glass powder content relationship:* The relationship between glass powder content and voids filled with asphalt is shown in figure 10. Voids filled with asphalt; the value increased with an increase in replacement rate of glass powder until it reaches the highest VFA value at 75% Waste glass powder (WGP). It was noticed that the VFA for replaced mixes with 0% to 100% glass powder, all are within the range of 65% - 75% specified by ERA Pavement Design Manual. At 75% replacement rate of glass powder content, the VFA in the mix is the highest value indicating the lowest air void for the mix. The VFA for the control mix was lower than the 75% of the replaced mix. This result was due to more effective bitumen content that was present in the mix to fill available voids between the inter-granular spaces.

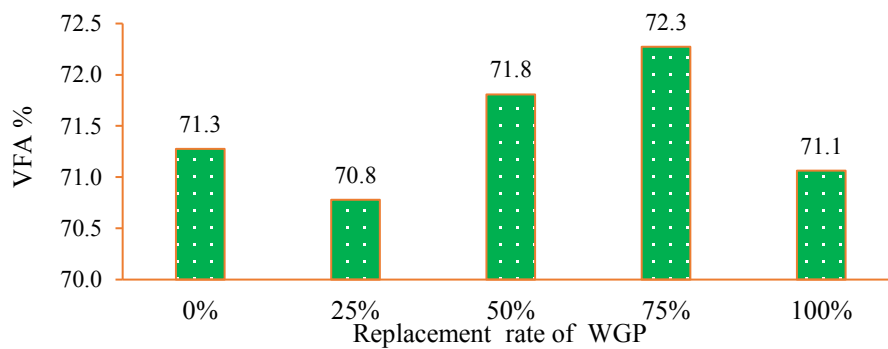


Fig. 10 Relationship between VFA and replacement rate of WGP fillers at constant bitumen content of 5.10%.

7) *Summary of Properties of Asphalt Mix with Various Glass Powder Content*: Table X indicated that each of Marshall's Stability, bulk density, and VFA increase as the glass powder increases. The Flow values, air voids, and void in mineral aggregates decreased as the glass powder content increases.

TABLE X

MARSHALL PROPERTIES OF ASPHALT MIXES WITH DIFFERENT WGP FILLER CONTENT

Material Properties	Waste Glass Powder (WGP) Content				
	0%	25%	50%	75%	100%
% of Bitumen	5.10	5.10	5.10	5.10	5.10
Stability (kN)	10.1	10.4	11.0	12.0	10.3
Flow (mm)	3.26	2.96	3.12	2.84	3.10
Bulk Density (gm/cm ³)	2.350	2.352	2.356	2.360	2.355
% of Va	4.2	4.3	4.1	4.0	4.2
% of VMA	14.8	14.7	14.6	14.4	14.6
% of VFB	71.3	70.8	71.8	72.3	71.1

D. Determination of Optimum Glass Powder Content

Asphalt mix with the calculated optimum content satisfied the maximum Stability, maximum bulk density, Va within the allowed range of specifications. From figure 10, it could be noticed that all values of Marshall stability for various glass powder content satisfied the local and international specifications, which were in the minimum of 7.0kN and 8.006kN, respectively. However, the maximum stability corresponding to 75% of glass powder content found out to have 12.0kN. Figure 7 showed the bulk density values at various glass powder content and the maximum bulk density obtained at 75% glass powder content. Figure 8 showed that all the values of air voids percentage at various glass powder content at 75% Waste glass powder filler content, the corresponding air voids value was 4.0%, which is the median air voids in the specifications.

Therefore, the mix obtained using 25% CSD and 75% WGP met the standard in terms of maximum Stability, maximum bulk density, and Va within the allowed range of specifications, at an optimum bitumen content of 5.10%. Hence, 75% was adopted as the optimum content of glass powder.

E. Comparison of Properties of Asphalt Mix at Optimum GPC With Local and International Specifications

The comparison was made on Marshall and volumetric properties of asphalt mix at optimum glass powder content of 75% by weight of the optimum crushed stone dust filler with local and international specifications. Table XI indicated the asphalt mix with an optimum glass content of 1.625% CSD and 4.875% WGP by weight from the total component of aggregates or simply 75% by weight of crushed stone dust filler satisfying the requirements of Ethiopian Road Authority (ERA) Pavement Design Manual 2002, and the Asphalt Institute Specifications for all tested properties. Therefore, the use of glass powder with a maximum replacement of 75% WGP by weight of crushed stone dust filler or 4.875% by weight of aggregate is advisable.

TABLE XI

COMPARISON OF THE PROPERTIES OF ASPHALT MIX WITH OPTIMUM WGP

Marshall Method Mix Criteria	Asphalt mix replaced by 75%WGP	ERA Standard Specifications		Asphalt Institute Specifications		Remarks
		Traffic Heavy		Traffic Heavy		
		Min	Max	Min	Max	
No. of blows	2*75	2*75		2*75		
Stability (kN)	12.0	7.0	-	8.006	-	Satisfied
Flow, (mm)	2.84	2	4	2	3.5	Satisfied
Va, %	4.0	3	5	3	5	Satisfied
VFA, %	72.3	65	75	65	75	Satisfied
VMA, %	14.4	13	-	13	-	Satisfied

IV. CONCLUSIONS

The laboratory test for Waste glass powder performed for gradation and plasticity index, hence, satisfying the Standard Specification for use as a filler in hot mix asphalt concrete production. Likewise, the Optimum filler content of Crushed stone dust (CSD) was determined on the basis of the maximum Marshall stability test. It was found out that 6.5% filler content of CSD indicated a maximum Marshall stability at 5.10% bitumen content. Further, the laboratory experiment based on each test result for Marshall stability, bulk density, and VFA showed an increased value as the glass powder increases. The flow values, Air voids, and void in mineral aggregates decreased as the glass powder content increases. At 75% replacement of crushed stone dust by glass powder, the mixture indicated maximum Stability, maximum bulk density, and Va within the permissible range of the Standard Specifications. Therefore, the percent content of glass powder at 75% by weight of Crushed stone dust (CSD) filler or containing 4.875% by weight of aggregate can provide optimum performance for heavy traffic.

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