Effect of Using Fine Volcanic Ash Instead of Crushed Basalt Filler in Hot Mix Asphalt

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https://doi.org/10.59222/ustjet.2.1.1

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Abstract:

Numerous studies over the years have demonstrated the significance and impact of filler in influencing the physical and mechanical properties of Hot Mix Asphalts (HMAs). To overcome such issues, as environmentally friendly alternatives, several different materials for construction have been proposed. This led to an investigation into the potential use of fine volcanic ash (FVA) as a hot mix asphalt filler alternative. In order to prepare bituminous concrete mix sample with conventional basalt filler (BF) as control mix. The Marshall Mix design approach was used to calculate the effective bitumen content. A total of 15 bituminous concrete mix specimens with bitumen content of 4%, 4.5%, 5%, 5.5%, and 6% were created, and the optimum asphalt content was 5.24 %. The impacts of five different (FVA) samples with filler contents of 15%, 30%, 45%, and 60% by weight were compared with respect to bituminous concrete performance. The Marshall stability of a total of 30 samples with varying amounts of (FVA) were investigated. The outcomes were compared with a conventional bituminous concrete mixture. The results showed that fine volcanic ash may substitute 30% of the basalt filler at a bitumen content of 5.24%, 13.84 KN Marshall stability value, 4.0% air voids, 74.77% VFB, 2.380 g/cm3 bulk density and 3.54 mm flow. Therefore, the combination of 30% Fine Volcanic Ash by weight of Basalt Filler satisfies the ASTM Specifications, while the remaining VA content satisfies the basic requirements of the ASTM Specifications.

Keywords: volcanic ash, bituminous mix, filler, experimental testing, Marshall stability.

https://doi.org/10.59222/ustjet.2.1.1

تأثير استخدام الرماد البركاني الناعم بدلا من المواد المالئة البازلتية المسحوق في الخلطة الاسفلتية الساخنة

الملخص:

أثبتت العديد من الدراسات على مر السنين أهمية وتأثير المواد المالئة على الخواص الفيزيائية والميكانيكية لخليط الاسفلت على الساخن. للتغلب على هذه القضايا، كبدائل صديقة للبيئة، تم اقتراح عدة مواد مختلفة للبناء. وقد أدى ذلك إلى إجراء تحقيق في امكانية استخدام الرماد البركاني الناعم كبديل لمواد المالئة الإسفلت الساخن. ولتحضير عينة من خليط الخرسانة البيتومينية بالمواد المالئة البازلت التقليدي كخلطة مرجعية فقد تم استخدام طريقة تصميم مارشال لحساب المحتوى الاسفلتي الفعال، حيث تم عمل إجمالي 15 عينة من الخلطة الخرسانية البيتومينية بمحتوى اسفلتي 4 %، 4.5 %، 5 %، 5.5 %، و6 %، وكان محتوى الأسفلت الأمثل 5.24 %. تمت مقارنة تأثيرات خمس عينات مختلفة من خليط الاسفلت با لرماد البركاني الناعم بمحتويات المواد المالئة 15 %، 30 %، 45%، و60 % بالوزن ، ودراسة أداء الخرسانة البيتومينية. تم دراسة ثبات مارشال لمجموع 30 عينة بكميات متفاوتة من الرماد البركاني الناعم ومقارنة النتائج مع خليط الخرسانة البيتومينية التقليدية. أظهرت النتائج أن الرماد البركاني الناعم يمكن أن يحل محل 30 % من المواد المالئة البازلت التقليدي بمحتوى اسفلتي 5.24 %، قيمة ثبات مارشال 13.84 كيلو نيوتن، فراغات هوائية 4.0 %، 74.77 % فراغات ممتلئة بالأسفلت، كثافة الظاهرية 2.380 جم/سم3 وتدفق 3.54 ملم. بتالي فان نسبة 30 % من الرماد البركاني الناعم من وزن المواد المالئة البازلت التقليدي يفي بمواصفات ASTM، في حين أن بقية النسب المختلفة التي تم استخدامها في هذا البحث تلبي المتطلبات الأساسية لمواصفات ASTM.

الكلمات المفتاحية : الرماد البركاني؛ مزيج البيتومين، مواد مالئة ؛ اختبار تجريبي؛ ثبات مارشال.

1. Introduction

Hot mix asphalt (HMA) has faced increased demands for water stability, low-temperature crack resistance, and high temperature stability to get superior quality and longer service life with the rapid advancement of knowledge and technology [1]. Numerous research projects on waste and byproducts use have been carried out in the building and construction industry. If waste is successfully incorporated into cement and bituminous concrete, environmental pollution will be reduced, an efficient solution will be offered, and the performance of the changed structures will finally be improved[2] . Among the wastes used as modifiers in cement and bituminous concrete are wood bottom ash, sugarcane fiber, coal fly ash, polyethylene terephthalate, alkali activated slag, powdered granulated blast furnace slag and rubber [3]; [4]. An appropriate engineering concern list, including effects on production, strength and durability, and future recyclability; an environmental concern list, including processing and handling techniques, leaching, emissions, and fumes; and an economic concern list, including salvage value, life cycle costs, and funding shortages, are included with the engineering feasibility of using waste materials[5]. The filler, a non-plastic material used to improve the characteristics of a mixture, eliminate plasticity, and reduce volume change, predominantly passes sieve No. 200 (0.075 millimeters), making it a much more essential material.

Volcanic ash is magma-fragmented natural pozzolanic NPs. VAs' properties are affected by the physical and chemical changes that occur during their creation. For example, the leaching process or the environment throughout the weathering process might modify the chemical and mineralogical characteristics of VAs [6]. One type of tephra is VAs (air volcanic extrusion), which typically causes damage initially but eventually has beneficial effects. Sand and silt have particles ranging in size from 0.001 mm to 2 mm, while volcanic ash is insoluble[7] Volcanic glass, minerals, and pyroclastic rocks are known as VAs with diameters smaller than 2 mm that occur during a volcanic eruption [8]. Material deposits of VAs cover around 0.84% of the total land area in the world, or 124 million hectares, with most of them located in tropical areas [9]. The most common type of minerals in VAs are silicate minerals. Three categories exist for silicate minerals: feldspars, which include albite and anorthite; amphiboles, which comprise tremolite; and pyroxenes. which include augite and diopside, as well as less frequent quartzes [10]; [9]. W. Liu et al. examined four different varieties of asphalt cement including fine fillers made of volcanic ash at the nanoscale, showing that the shape of the stable cycle strain curve is unaffected by the aggregate skeleton and load size[11]. It has been noted that mastic produces a solid packing-SBS-binder system may improve the mechanical characteristics of styrene-butadiene-styrene (SBS) and enhanced mixes as a result of the complex geology and high volcanic ash porosity [12] A. Diab and M. Enieb studied the way VA asphalt glue performed on roads and found that bituminous glue's low heat resistance and asphalt mixes' exceptional heat resistance could both be greatly improved by natural VA [13]. In order to solve the issue of over-dependence on limestone, [14] investigated the use of volcanic rocks rather than limestone in road pavements. The use of volcanic stone was researched and assessed in terms of fundamental performance experiments using asphalt mastics with varying quantities of powdered volcanic rock and limestone powder. The results suggest that the VSP with asphalt mastic outperformed the limestone powder in terms of basic performance. With VSP, asphalt mastic's high temperature performance increased by 17.6%, but its low temperature performance remained almost unchanged. In the meanwhile, limestone powder might not be as effective in bonding asphalt as volcanic stone powder. It was demonstrated that certain limestone powder might be substituted with volcanic stone powder as an inorganic filler.

Other studies focused into how to improve the fatigue and creep resistance of HMA by using granular volcanic ash in mix design rather than coarse aggregate [15]. The literature research indicates that using different VA levels has different effects on the stability and strength of asphalt concrete. According to the best of the authors' abilities, there has been no extensive study of the combination of VA in asphalt concrete in the literature.

2. Objectives of the Study

The objectives of this study are to:

- Investigate FVA as a filler element in asphalt mixture manufacture.
- Reduce environmental pollution by utilizing waste FVA in flexible pavement.

3. Research Methodology

3.1. Materials and Methods

The study's overall activity plan is shown in Figure 1. Materials employed in this experiment included asphalt with a 60/70 penetration grade, BF, and FVA. Volcanic ash was added to the mix in increments of 0-60% to demonstrate. It has an impact on the volumetric characteristics and performance of asphalt mixtures.

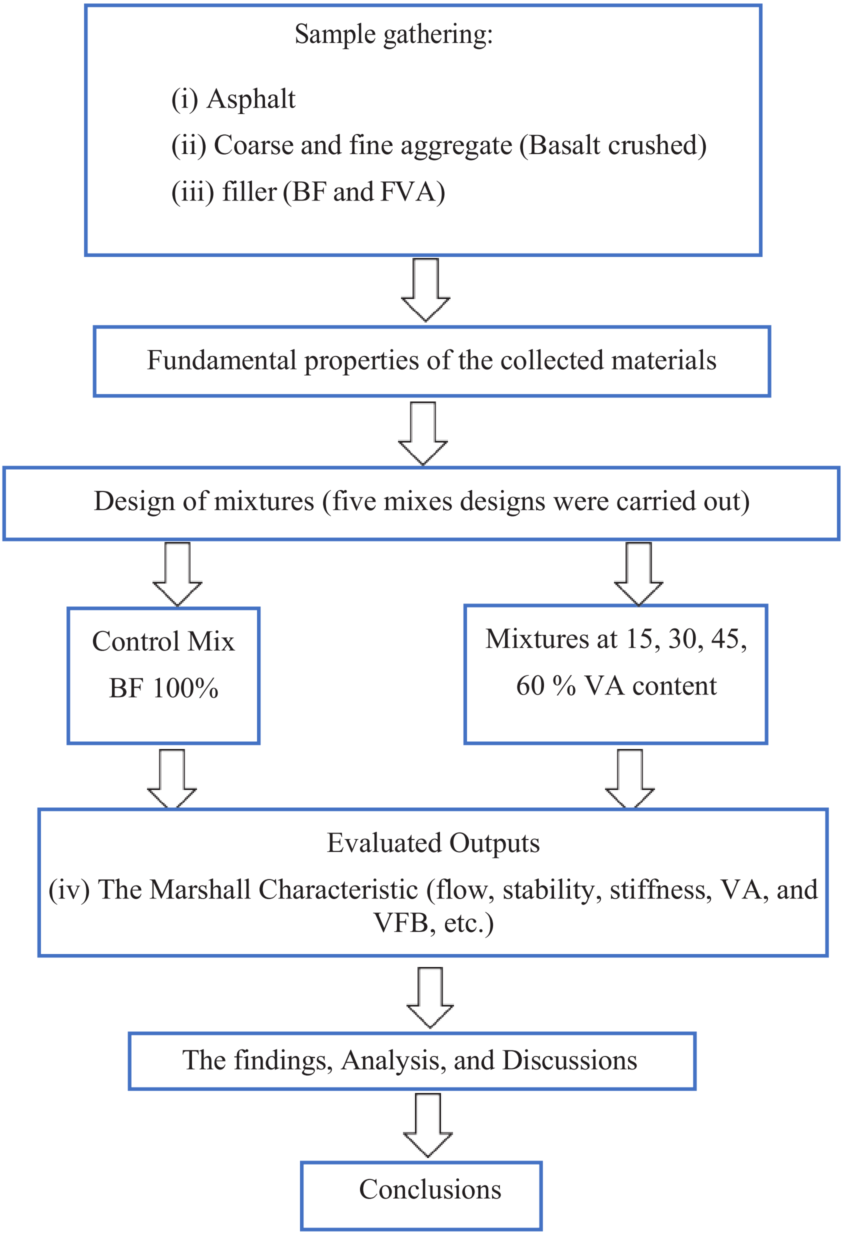

Figure 1: Activity Framework

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3.2. Material used

3.2.1. Asphalt

Asphalt cement (AC) 60/70 manufactured at Oman Refinery was brought to the site (by bulk), utilized to create the investigated mixes throughout this investigation. According to AASHTO standards, asphalt cement is tested in a lab to determine the degree of penetration. Table 1 lists the characteristics of the asphalt binder.

Table (1): Asphalt Characteristics

characteristics	Designation No. AASHTO.	Result	AASHTO Specification
Penetration at 25 co, 0.1mm	T 49	62	60-70
Flash point, co	T 48	235	≤ 250
Specific gravity	T 228	1.028	1.01-1.06
Softening point, co	T 53	51	46-56

3.2.2. Aggregates

Four sizes of aggregates are collected from source AL-Amjad crusher plant, right side from Sana'a Mareb main road. The aggregate source is rock formed hills. The formation is columns basalt of igneous origin. These aggregate fractions have been tested to determine their suitability for using according to AASHTO, ASTM standard. NMAS stands for nominal maximum aggregate size of 12.5 mm was used to generate the mixture. Fig. 2 displays the gradation of the combined aggregate as well as the specified limit. The aggregate gradation employed in this study is dens-grade, which was used to meet the requirements of the wearing surfaces (BS EN 13108-1) as indicated in Table 2. Table 3 shows the basic characteristics of the aggregate used in this investigation.

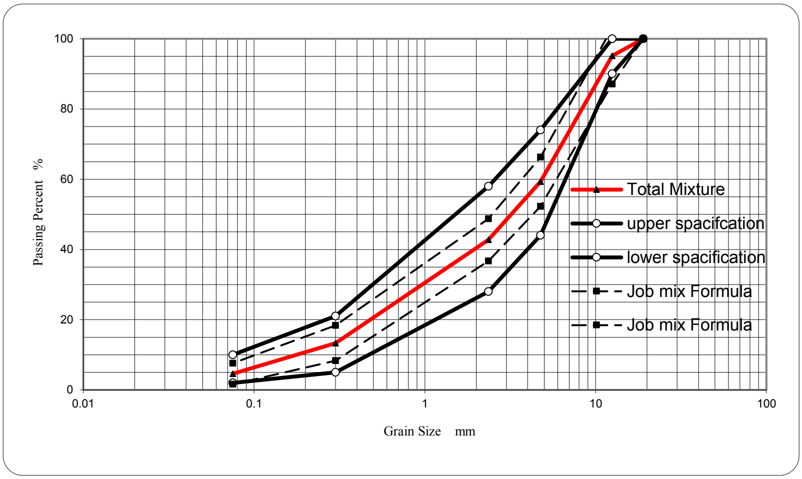

Figure 2: Grain Size Distribution of Aggregate Used

Table (2): Aggregate Gradation

Sieve size (mm)	Used gradation (% pass)	Specifications limits (% pass)	Mean Specification. (% pass)
19.5	100	100	100
12.5	95.13	90 - 100	95
4.75	59.3	44 - 47	59
2.36	42.7	28 – 58	43
0.3	13.3	5 – 21	13
0.075	4.6	2 – 10	6

Table (3): Fundamental Characteristics of the Aggregate

Items	Actual Value %		Specification Limit
1-Specific Gravity and Water Absorption T 84, 85 and C 128:	Specific γ	W abs	AASHTO T84, T85
Fraction 19.5-12.5b mm	2.854	0.959	4 Max. for W absorption
Fraction 12.5-09.5 mm	2.726	2.018	
Fraction 09.5-4.75 mm	2.886	2.098	
Fraction 4.75-minums mm	2.623	2.872	
2- Lose Angeles Abrasion T96	12.7		25 Max.
3- Plasticity Index (PI) T 89 and D 4318	Non – Plastic		Non – Plastic
4- Sand Equivalent T 176	90.5		75 Min.

3.2.3. Volcanic Rocks Ash

Surface geology in various sections of Yemen is dominated by Quaternary Volcanic outcrops. Figure 3 depicts a map of the principal granular volcanic ash locations, with an estimated surface area of 17,000 km2 [16]. Many volcanic ash locations both in cities and suburbs. So yet, this material has not been used in engineering. Due to its availability in many regions in great quantities and at no cost, this kind of material is one of the substitutes that can be applied to the building of roads. The rocks use in this study were dark gray-brown.

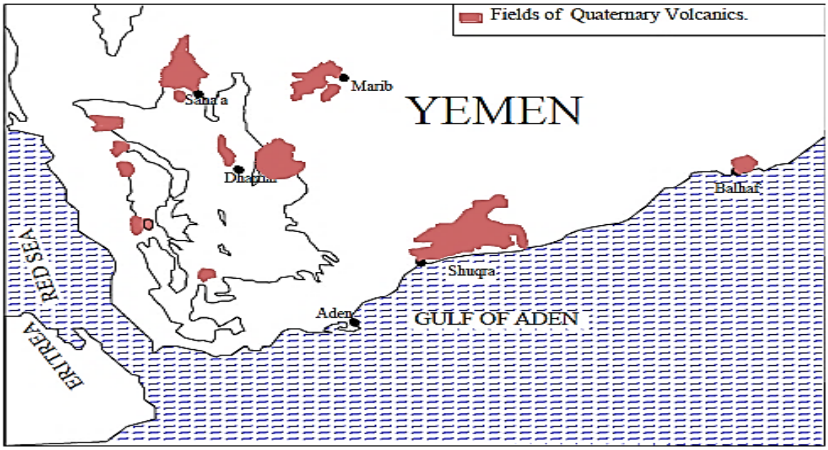

Figure 3: Yemen's Main Sources of Quaternary Volcanic Ash

Figure 4: Volcanic Stone

Figure 5: Volcanic Stone Ash

As illustrated in Fig. 4, the particle size of the rocks is regulated below 15 cm. Non-volcanic rocks were removed from the mix after the stones were uniformly mixed. The volcanic stone ash was generated by following these steps:

The shelf-type abrasion tester from Los Angeles was filled with the crushed volcanic rocks and operated for 1 hours; The ash and pulverized stone residue were filtered through a sieve with a 0.075 mm particle size after the Los Angeles abrasion test. The volcanic rocks ash needed for the test, as indicated in Fig. 5, was the ash that was left over after flotation.

Tables 4 and 5 provide an overview of the volcanic ash index characteristics and chemical content, respectively [15].

Table (4): Characteristics of Volcanic Ash

Properties	Value
Specific gravity	2.44
Plasticity index	1.2

Table (5): Chemical Composition of Volcanic Ash

Component	SiO2	TiO2	(Al2O3)	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LiO	Total
Percentage (%)	47.20	1.70	19.20	11.60	0.80	4.20	8.10	4.80	1.20	0.50	0.5	99.5

4. Experimental Procedures

4.1. Mixture Design

In this study, Marshall Test Method, also known as ASTM D1559 we use it because of a shortage of suitable Yemeni testing facilities (specifically, Gyratory Compactor Superpave). It was used to create asphalt concrete mixes and analyze their qualities.

4.1.1. Marshall Test

this study used the Marshall procedure (ASTM D1559) and we followed the standard specifications as shown in table 6. Five mix design, with different VA percentage of 0, 15, 30, 45 and 60 % of total filler weight. As a control mix, the 0% ash content mix design was employed with BF filler.

Table (6): Marshall Parameter Specifications

Description	Specification
Compaction blows	75
Stability (KN)	9 Min.
Flow (mm)	2- 4
VFB%	65-75
Air Voids %	3 – 5
Rigidity Ratio (stuffiness)	3 Min

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In each mix design, five asphalt content percentages were used: 4%, 4.5%, 5%, 5.5%, and 6% by sample weight. The temperatures for mixing and compaction were 160°C and 143°C, respectively. There were 15 asphalt concrete samples of 4 inches in diameter made, three for each bitumen percentage. After being heated, the samples were put in a mold and compacted rapidly. in the compactor after correctly mixing the aggregate and bitumen. 75 blows were applied to each side (top and bottom) of the compactor. The examples of asphalt concrete prepared for the Marshall test are depicted in Figure 6.

Figure 6: Samples of Asphalt Concrete for Tests of Marshall Stability

Several tests were run on the samples that were collected after the Marshall Mix samples. The Marshall flow parameters and stability, as well as the mix's bulk specific gravity (Gmb) and theoretical maximum specific gravity (Gmm) were all tested to determine the bituminous mix's characteristics and choose the mix that meets the necessary requirements. The volumetric characteristics of Marshall Mixture samples were calculated using Gmm and Gmb in order to evaluate the mix's quality. The Marshall Standard Test is performed by immersing compacted asphalt concrete samples in hot water for 30 to 40 minutes at the standard test temperature of 60CO, followed by diametrical loading at a rate of 50.8m/min. The effective bitumen concentration (EBC) of freshly made conventional samples was measured using Marshall stability and flow parameters in accordance with ASTM standards. The effective bitumen percentage was determined by experiments on conventionally prepared samples.

5. Results and Discussion

5.1. Effect of Adding VA on Marshall HMA Characteristics

5.1.1. Determination of Optimum Asphalt Content of Control Specimen

Five different percentages of asphalt cement are tried (4, 4.5, 5, 5.5, and 6%) by weight of aggregate (1200 grams), with the gradation utilized in this study being dense graded for surface course. Three Marshall specimens are made and tested for each percentage. The optimal asphalt content (OAC) is determined as an average asphalt content value corresponding to maximum unit weight, maximum stability, 70% voids filled with bitumen VFB and 4% air voids (AV). While the flow is being verified in accordance with the ASTM specification. Table (7) shows the obtained Marshall properties at the OAC and the specification limits and figure 8 shown the Marshall test plotted curves.

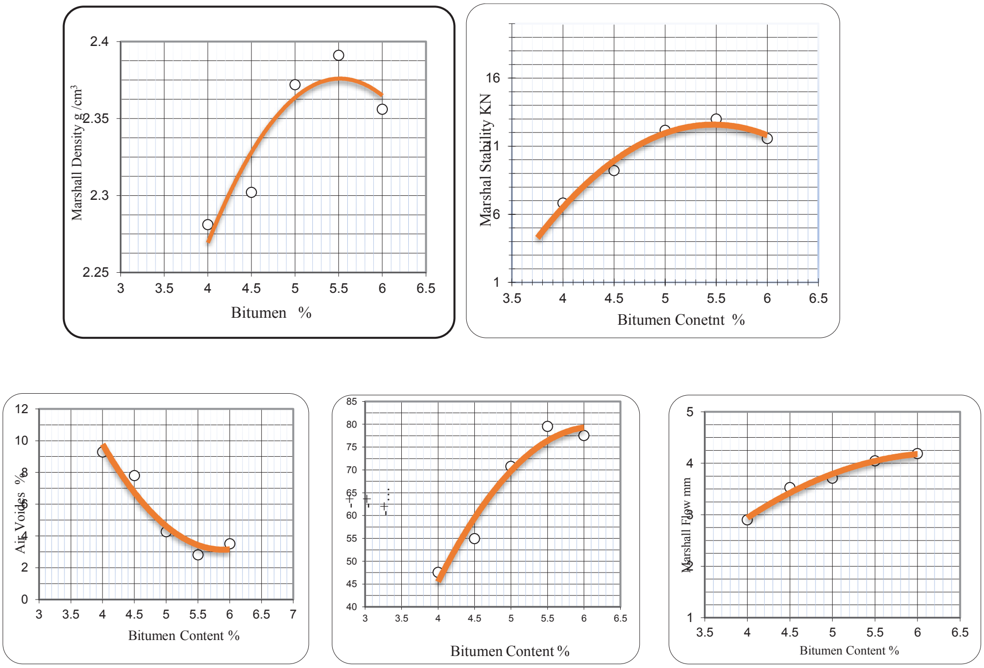

Figure (8): Marshall Test Results for Control Mix

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Table (7): Marshall Characteristics for Control Mix

Marshall Characteristics	(OAC) %	Stability KN	Flow (mm)	Rigidity Ratio KN/mm	Unit Weight gm/cm3	AV%	VFB%
Value	5.245	12.771	3.86	3.293	2.361	4.87	71.22
Specification Limits	(4.00 – 11.00)	9 Min	(2 - 4)	3 min	---------	(3-5)	(65 -75)

5.1.2. Effect of Adding VA on Marshall Mix Characteristics

Three Marshall specimens are made and investigated at each percentage, yielding a total of 15 specimens for the VA additive and 15 specimens for the control mix. For both control and treated specimens with VA, Marshall characteristics (Stability, Flow, unit weight, AV%, and VFB%) are computed. Marshall property results are shown as relationships between (Stability, Flow, unit weight, AV%, and VFB%) and asphalt content (AC). Another graph shows the mixture stiffness (stability/flow) ratio as a function of AC and VA percentage. The VA utilized is employed in amounts of 15, 30, 45, and 60 % of the filler's total weight. The relation between the stability that was attained and the VA percentages at the optimal asphalt content (OAC) is depicted in Figure 9.

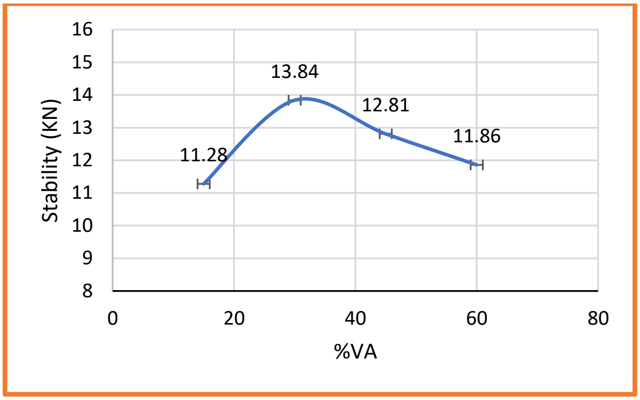

Figure (9): Effect of FVA on Marshall Stability at (OAC)

Figure 9 demonstrates that at 30% VA, the maximum stability value occurs, and the stability increases from 11.28 KN to 13.84 KN, representing a 22.70% improvement. This could be attributed to the penetration of tiny particles VA into mixture voids, resulting in a dense volume. The new mixture withstands the applied force and appears to improve stability. Figure (10) depicts the associations between flow and AC at the OAC for each VA percentage. It is clear the flow drops with an increase in VA percentage up to 30% and subsequently increases with an increase in FA. At 60% FA, the maximum flow value is attained. Height flow values within the acceptable range imply strong flexibility, increasing the ability of HMA pavement to deform without cracking.

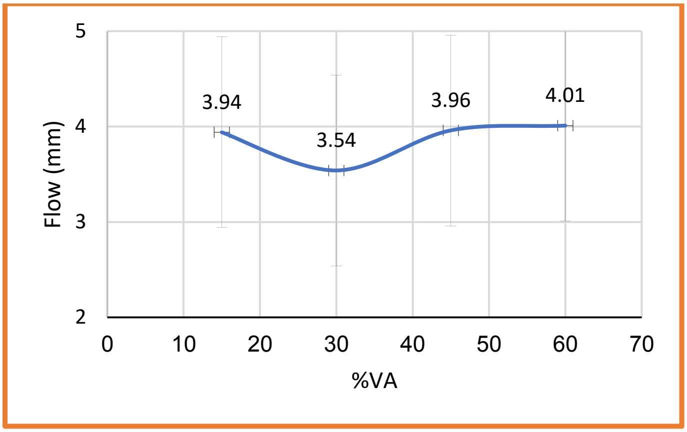

Figure (10): Effect of VA on Marshall Flow at (OAC)

Figure (11) shows that the value of unit weight increases up to 30% of the VA content before decreasing. Except for 15%, The adjusted mixtures' unit weight values are all greater than the value of the control mix. Because of the presence of microfine particles (VA) in the HMA, the mix is denser than the control mix, resulting in an increase in unit weight.

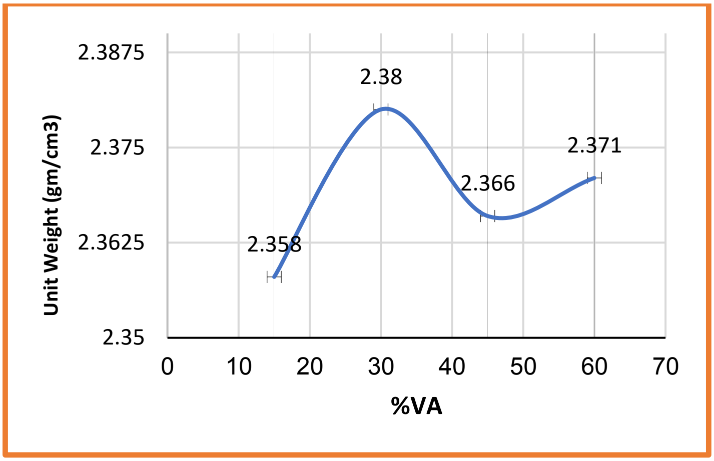

Figure (11): Effect of FVA on Marshall Unit Weight at (OAC)

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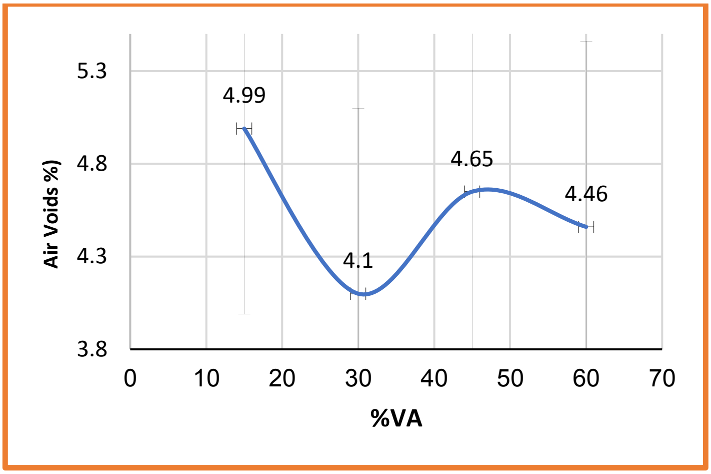

Figure (12): Effect of Adding VA on AV % at (OAC)

Figure (12) indicate that when the SF percentage grows up to 30%, the AV% falls and subsequently increases.

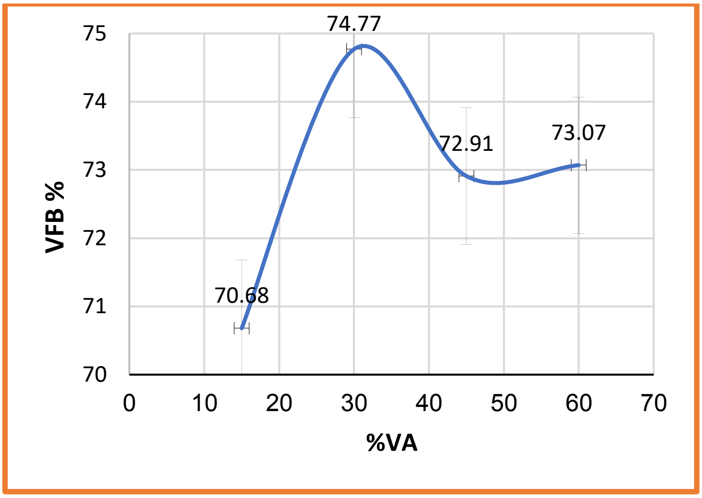

Figure (13): Effect of Adding VA on VFB % at (OAC)

The variation in VFB% after adding FA to asphalt mixes is seen in Figure (13). At 30% VA, the max value of VFB% is achieved. Conversely, at 45% VA, the minimal value of VFB% is reached. and all these values fall inside the range of the specified limits. The mix stiffness is calculated by dividing the Marshall stability by the flow value in KN/mm. The correlations between the asphalt content and stiffness at OAC for varying VA percentages. The relationship between stiffness and SF concentration at OAC is shown in Figure (14). It demonstrates that the mix stiffness rises with the VA percentage up to 30% and then decreases. First, because of the increased stability when the flow was still low, there was an initial rise in stiffness. However, as the VA increased, the flow steadily increased, resulting in a drop in total stiffness. Furthermore, it is notable that the 30% VA stiffness value is greater than the control mixture.

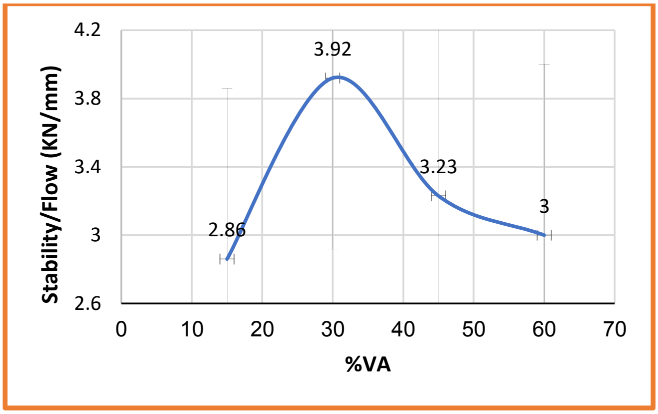

Figure (14): Effect of Adding VA on Marshall Stiffness % at (OAC)

Modifying the HMA with VA significantly enhances the bitumen's characteristics. Marshall stiffness increases by approximately 17.47% as a result of the VA's approximately 22.70% and 7.77% increases in Marshall stability and flow, respectively. While keeping the AV% within allowable limits, the VA raises the modified mix's unit weight. The ideal VA content to attain ideal mix characteristics is 30% of the filler's weight. The effects of adding various percentages of VA on the characteristics of the asphalt mixture are displayed in Table (8).

Table (8): Effect of Adding VA on Marshall HMA Properties

VA Percentage	O.A.C %	Stability KN	Flow (mm)	Unit Weight gm/cm3	AV %	VFB %
0%	5.24	12.77	3.86	2.361	4.87	71.22
15%	5.24	11.28	3.94	2.358	4.99	70.68
30%	5.24	13.84	3.56	2.380	4.1	74.77
45%	5.24	12.81	3.96	2.366	4.65	72.91
60%	5.24	11.86	4.01	2.371	4.46	73.07

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6. Conclusions

Considering the test results, the following conclusions can be drawn:

- The maximum Marshall stability at 5.24 percent bitumen percentage was discovered to be suggested by BD's 4.6% filler content.
- The bulk density, VFB, and Marshall stability test results for each laboratory experiment indicated a higher value as the VA increased by up to 30%.
- Volcanic ash added as filler to the HMA has significantly enhanced the mixture's performance regarding its volumetric characteristics.
- The percentage of fine volcanic ash increases, the flow values, air voids, and void field with bitumen decrease.
- The mixture showed maximum stability, minimum flow, maximum bulk density, flow, and VA falling within the Standard Specifications' allowed range at 30% replacement of basalt dust by fine volcanic ash.
- The other concentration of VA gives us results in the limit specification. For heavy traffic, the VA percent content of 30% by weight of basalt filler can therefore offer the best performance.

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