

## The Effect of Animal Bone Ash on the Mechanical Properties of Asphalt Concrete

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### Abstract

For the sake of enhancing the mechanical properties and durability of asphalt concrete, many studies suggest adding different admixtures, such as waste materials in the form of filler. These admixtures have a significant influence on the performance of asphalt concrete by plying a roll in filling the voids between particles and sometimes as a cementitious material. This study aims to improve the strength of asphalt concrete by adding crushed animal bone to the mix after carbonization at a temperature of 800 Co. Seven different percentages (10, 20, 30, 40, 50, 60, and 100%) of animal bone ash as a replacement for the filler percentage were added to the optimum asphalt concrete mix. A number of tests were conducted on asphalt concrete specimens to measure Marshall stability (MS), Marshall flow value (MF), voids filled with asphalt percentages (VFA), air void percentages (VA), voids in mineral aggregate percentages (VMA), and maximum theoretical specific gravity (GMM). From the results, the maximum stability of 14.85 KN was reached when using animal bone ash of 20% as a partial replacement for the conventionally used filler (limestone). In general, there are some improvements in the physical properties of asphalt concrete with animal bone ash, which can be related to the increase in the bond between the particles of aggregates and the bitumen material.

*Keywords:* Mechanical Properties; Asphalt Concrete; Filler Materials; Animal Bone Ash.

### 1. Introduction

Recently, the demand has increased to find an asphalt mix capable of resisting various external loads and minimizing cracking. The designed life span for pavements is usually 20 years with consideration of the expected traffic loads. Thom & Elliott (2009) stated that the high stiffness modulus of asphalt can achieve a pavement that is capable of resisting high traffic loads without cracking [1]. Previous researchers such as Zaumanis & Mallick (2014) [2] have confirmed that using waste or by-product materials to replace coarse or fine aggregates or even filler results in a promising evolution in asphalt concrete mechanical properties and durability. Yan et al. (2013) [3] concluded that the filler has a great effect on the life span of the asphalt mix because it increases the resistance to water penetration and improves the asphalt viscosity, besides the high influence on the strength. So, the properties of the filler materials in asphalt mix design are very important in physical and chemical aspects, as stated by Muniandy et al. (2013) [4]. In addition, recently there has been an increase in the demand for construction materials, especially in road construction, beside the insufficient current resources, which led studies such as Clay et al. (2007) and Chudy et al. (2014) [5, 6] to search for an alternative, such as using waste materials.

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Besides that, the amount of solid waste produced from the consumption of natural resources has increased recently due to the increase in the population all over the world. In the next five years, the production of solid waste is expected to grow significantly to a large amount, which could lead to many environmental problems. Using waste materials in pavement can reduce the consumption of conventional highway materials, as a result, decreasing the extraction and processing costs of these materials. Some researchers suggest using by-products materials in replacing the materials of lower paving layers to use more quantity of waste material, but other studies dispute this opinion due to the cost of transportation and utilization of waste materials, and state that using these materials in the surface layer could be more worthwhile as Huang et al. (2007) [7]. So many researchers are concerned with using waste materials in construction as a replacement for ordinarily used materials. Most of the studies that used waste materials in the concrete mix or asphalt mix came up with some improvements in the durability and mechanical properties of the hardened construction material.

Bindu et al. (2020) [8] investigated the potential of using ashes from Cashew Nut Shells in asphalt mixes. As partial replacements for the very fine sand ingredient in the asphalt concrete, various quantities of ashes were used. The Marshall test was used to determine the mechanical characteristics of the mixes. The findings indicate that CNS ashes up to 15% can be used in place of fine sand in asphalt concrete.

Sung et al. (2008) [9] focused on using recycled waste lime to replace the filler in the asphalt mix. The results of this study indicate a good enhancement in stripping resistance and permanent deformation resistance at high temperatures. The impact of coal waste powder as a filler in hot mix asphalt was examined by Modarres and Rahmanzadeh (2014) [10]. Compared to the reference mix, the samples of asphalt with coal waste ash resulted in better stability and resilient modulus.

Al-Busaltan (2016) [11] chose two filler materials, namely Silica Fume (SF), and Rice Husk Ash (RHA), for up to 30% replacement of filler. The results showed that with less than 15% of SF, or 27.5% RHA, the HMA design satisfied the local specification requirements. Also Tahami et al. (2018)[12] stated that asphalt mixtures “with rice husk ash (RHA) and date seed ash (DSA) fillers showed higher stability and stiffness modulus in comparison with the control mixture. Also, using biomass ashes improved the thermal sensitivity of mixtures and the adhesive force between asphalt and aggregates, which caused an enhancement in rutting resistance and fatigue life of HMA mixtures”.

Also, the possibility of using fly ash was proved as a replacement for filler material in the asphalt mix by Sharma et al. (2010) and Choi et al. (2014) [13, 14]. Some other studies use different by-product materials to replace the filler materials, such as recycled brick powder by Chen et al. (2011) [15]. Choudhary et al. (2018) [16] investigated the effect of seven different waste materials on bitumen mix as filler, including glass powder, limestone dust, red mud, rice straw ash, brick dust, carbide lime and copper tailings. A number of mechanical properties were tested on the waste filler bitumen mixes, such as strength and resistance to moisture, rutting and cracking, in comparison with the cement filler bitumen mix. The results show that the properties of the waste filler mix were satisfactory and superior to the conventional filler. Waste mineral products (marble, granite and steel slag) were proposed as alternatives to traditional fillers by Tarbay et al. (2018) [17]. The findings revealed that marble has the potential to increase moisture damage resistance in terms of tensile strength ratio and stability loss.

Also, the rice husk ash was studied as a waste filler material in hot asphalt mix by Sargin et al. (2013) [18]. Four percentages of limestone were used as a conventional filler in the asphalt concrete mix (4, 5, 6, and 7%). The highest stability was achieved using 5% filler according to the Marshall Stability test. The rice husk ash was used by 25, 50, 75, and 100% in replacement of limestone filler. From the results, it can be observed that 50% rice husk ash with 50% limestone filler has the highest stability in comparison with the other percentages and the control samples.

Recently, animal bones, such as cow bones, have been generated in large amounts and sometimes it creates problems with disposal of these wastes. Because 15% of beef carcasses and 16% of lamb carcasses contain bone, the average solid waste output from a bovine slaughterhouse is 275 kg/ton of total live weight killed, or 27.5 percent of the animal's weight [19]. Animal bones after burning consist mainly of calcium and magnesium by 80 % and about 10% carbon and other substances, as Mohammed et al. (2012) [20]. Ali et al. (2019) [21] used traditional and dynamic rheometer testing methods to investigate the effects of adding Portland cement and waste animal bone on the characteristics of asphalt binder. The results demonstrate that adding both modifiers to the binder has a substantial impact on its characteristics. Increases in additive content resulted in decreased penetration, increased softening point, and increased flash point, implying improved stiffness and rutting resistance. As a result, animal bone ash might have some pozzolanic properties in hot asphalt mix. For this reason, this study concerned the use of animal bone ash (ABA) as a replacement for conventional filler material in hot mixed asphalt to increase the performance of pavements.

## 2. Materials and Experimental Work

### 2.1. Materials

Generally, hot mix asphalt is a combination of approximately 95% aggregates and 5% asphalt cement. The materials used in this study are crushed-animal bones (partially replacement of the conventional filler limestone), bitumen, and aggregates.

#### 2.1.1. Bitumen

The asphalt for this study was brought from the Al-Dora Iraq refiner. The tests that were conducted in this study on the bitumen material are listed in Table 1.

**Table 1. Physical characteristics of the bitumen**

Test name	Average values	Standard
Penetration (25C°)	40–50	ASTM D5 [22]
Flash point	180 C°	ASTM D92 [23]
Fire point	230 C°	ASTM D92 [23]
Softening point	45.5 C°	ASTM D36 [24]
Ductility (5 cm/min)	>100 cm	ASTM D113 [25]
Specific gravity	1.045	ASTM D70 [26]

#### 2.1.2. Aggregates

Aggregates of high quality were obtained from the quarries of Karbala, Iraq. The specifications of these aggregates are listed in Table 2.

**Table 2. Aggregate specifications**

Property	Standard	Results
Specific gravity of coarse aggregate (g/cm <sup>3</sup> )	ASTM C127 [27]	2.732
Bulk specific gravity of fine aggregate (g/cm <sup>3</sup> )	ASTM C128 [28]	2.641
Water Absorption of coarse aggregate (%)	ASTM C127 [27]	0.450
Aggregate Impact Value (%)	ASTM C131 [29]	12.90
Los Angeles Abrasion Value (%)	ASTM C131 [29]	16.70

The aggregates were prepared according to the standards of aggregate particle size distribution to improve the density and microstructure of the asphalt mix. Table 3 shows the aggregates that were repapered for the surface layer for this study by taking the average of the standard percentages of each size. In this experiment, the aggregates of all samples were prepared according to ASTM D5444 [30].

**Table 3. Gradation used in this study and gradation limits for surface coarse**

Sieve size		Gradation limits	Used gradation
Inch	mm		
¾	19	100	100
½	12.5	90-100	95
3/8	9.5	76-90	83
NO.4	4.75	44-74	59
NO.8	2.36	28-58	43
NO.50	0.30	5-21	13
NO.200	0.075	4-10	7

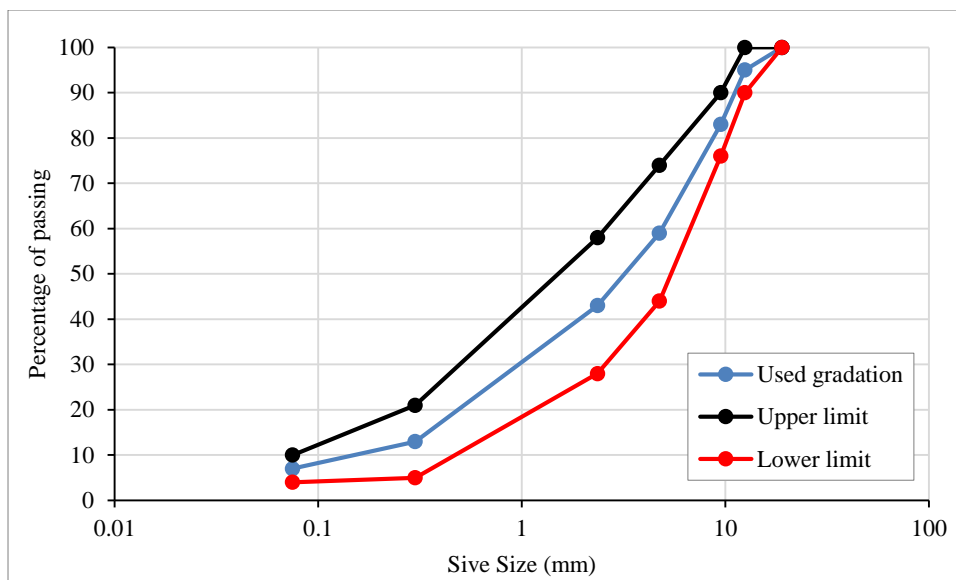


Figure 1. Grading of aggregates

2.1.3. Fillers

2.1.3.1. Limestone

In this study, limestone (LS) was used as a conventional filler in the asphalt mix, while animal bone after processing was used as a partial replacement for the filler content. The crushed limestone was obtained from quarries in Karbala, Iraq. The properties of limestone are illustrated in Table 4.

Table 4. Properties of limestone filler

Sieve Diameter	Property	Standard	Value
0.75 >	Specific gravity (g/cm <sup>3</sup> )		2.710
	Bulk specific gravity	ASTM C 127 [27]	2.690
	Water absorption (%)		0.12

2.1.3.2. Animal Bones (AB)

A large quantity of animal bones, especially cow bones, were collected from local markets. The bones were burned in an incinerator at 800 C° for two hours to ensure the complete burning of all bone pieces. The burned ash was left in the incinerator to cool down until it reached 25-30 C°, then the ashes were removed from the incinerator. The particle size of the resulted ashes was very small, so that almost all the ash particles passed through sieve No. 200.



Figure 2. Animal Bone Ash (ABA)

### 2.2. Experimental Procedure

The aggregates and the filler particles were dry mixed together, then added hot asphalt at the standard temperature and mixed well continuously to ensure that the aggregates were covered well with asphalt in accordance with ASSHTO T182 [31]. The coating should reach 95% at least.

Asphalt mixtures were prepared by the Marshall Method [32]. The following mechanical tests were performed on the asphalt mixture, including stability MS and flow MF according to ASTM D6927, 2015 [33], density Gmm, voids filled with asphalt VFA, voids in mineral aggregate VMA, and air voids VA according to ASTM D3203, 2016 [34]. Asphalt concrete samples were prepared using seven different replacements of limestone filler by ABA, including (10, 20, 30, 40, 50, 60, and 100%) as shown in Table 5. Three samples were prepared for each percentage to determine the average of each percentage for all results.

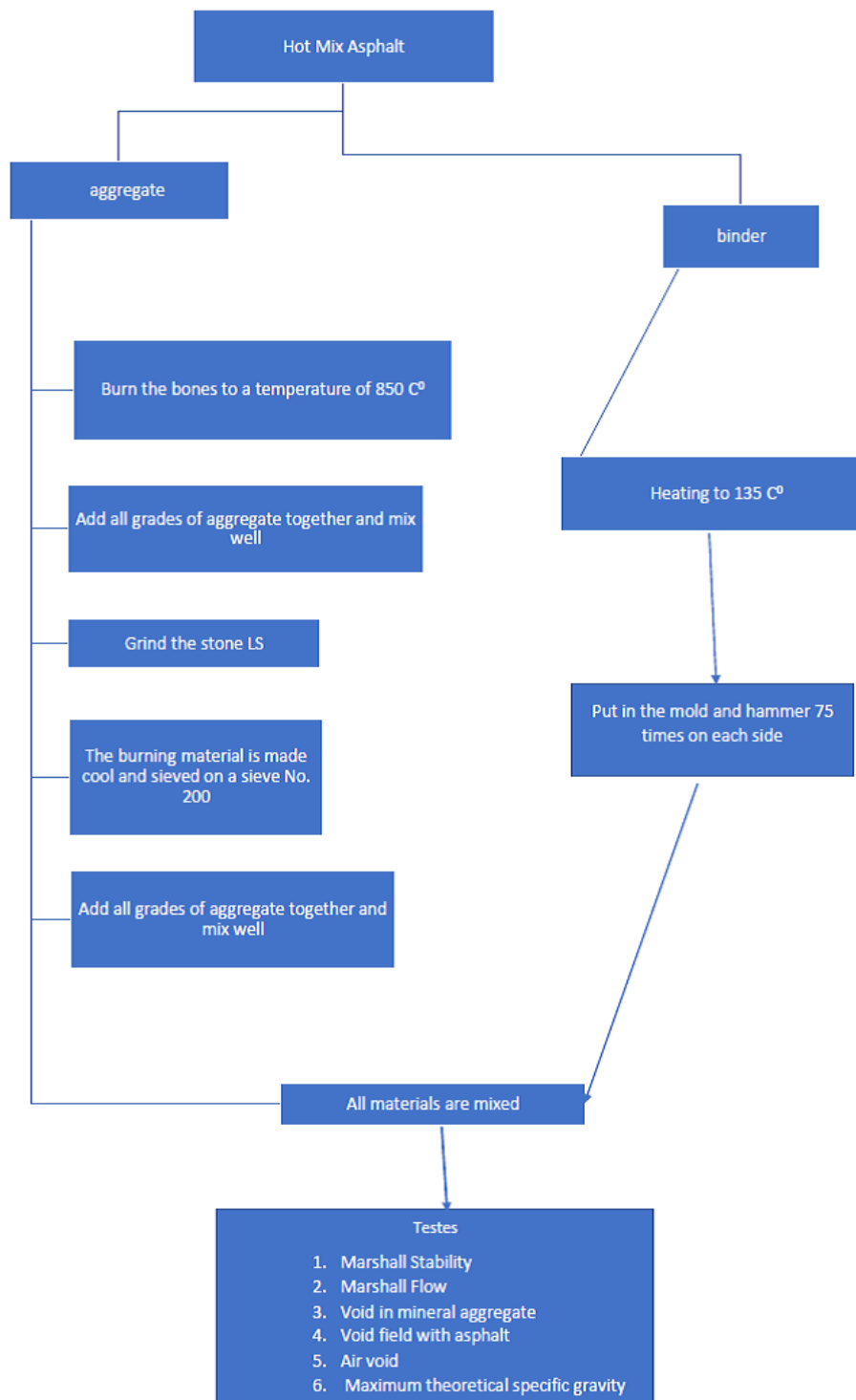


Figure 3. Research methodology flowchart



Figure 4. Asphalt sample hammer and Marshall Stability tester

Table 5. Filler percentage % for the asphalt mixes

Mix No.	Filler 7%	
	LS	ABA
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50
7	40	60
8	0	100

### 3. Results and Discussions

The Marshall stability MS gives an indication of the highest amount of load that can be applied to the HMA. As shown in Figure 5, for all the asphalt mixes with the control mix, the Marshall Stability test results were higher than the permissible limit, which is equal to 8 KN for the surface course [33].

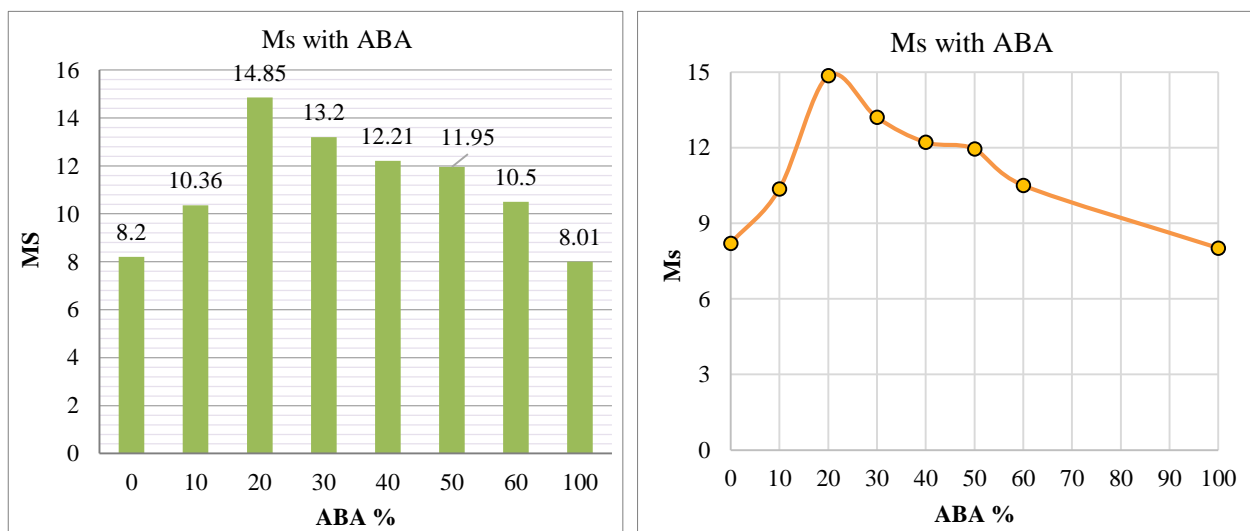


Figure 5. Relationship between MS and ABA%

The Marshall stability of the control asphalt samples was equal to 8.20 KN, while the maximum Marshall stability of 14.85 KN was reached when using 20% as a replacement of limestone filler by animal bone ash. So the Marshall stability increased by a high percentage of 81% when using 20% replacement from the control sample. While the replacement of 100% by animal bone ash results in the lowest stability of 8.01 KN. This might be due to the increased surface area of fine ABA particles, which strengthen the asphalt and improve its deformation resistance. However, continuous replacement of filler by ABA above 20% resulted in a gradual drop in Marshall Stability. This is because increasing the ABA % results in increasing the void ratio in the asphalt matrix.

According to [33], the acceptable flow limit range is between 2 mm as a minimum and 4 mm as a maximum for the surface course. The Marshall Flow value represents the flexibility and plasticity of the asphalt mixtures. Figure 6 shows that the lowest percentage of Marshall Flow is at the control mix, which is equal to 2.51 mm. The flow increases gradually with the increase in the animal bone ash replacement percentage, till reaching 4.15 mm flow for the 100% replacement of animal bones, which is the only percentage outside the standard. Thus, according to Marshall Flow, all replacement ratios are acceptable except for the 100% animal bone replacement ratio.

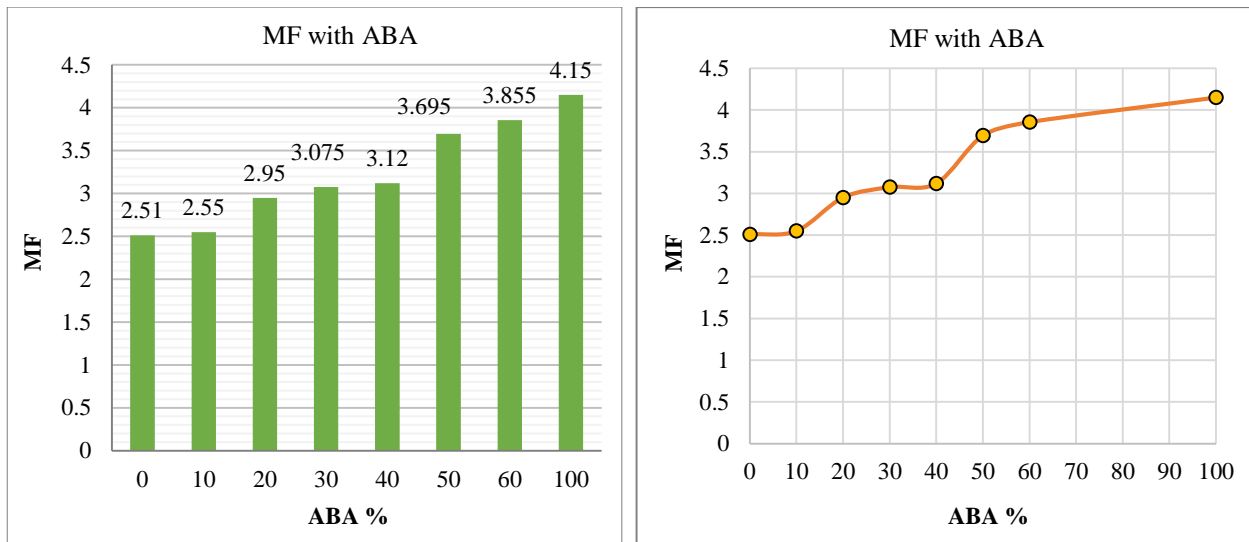


Figure 6. Relationship between MF and ABA%

Voids in mineral aggregates (VMA) are all the voids in the asphalt mix, including the air voids between the aggregate particles (VA) and the void filled with asphalt (VFA). According to [33], the acceptable value of VMA is not less than (14) %. Figure 7 shows that, in general, VMA increases with the increase in the percentage of ABA. As illustrated, the lowest percentage of VMA obtained is in the control mixture at 16.12%. The VMA stays approximately constant (16.15%) at the percentage of 10% ABA, then the percentage of VMA starts to gradually increase, reaching the highest percentage of VMA, which is 19.34% when the replacement ratio is 100% ABA. Thus, it can be figured out that all replacement percentages of ABA are acceptable according to the VMA limit of [34].

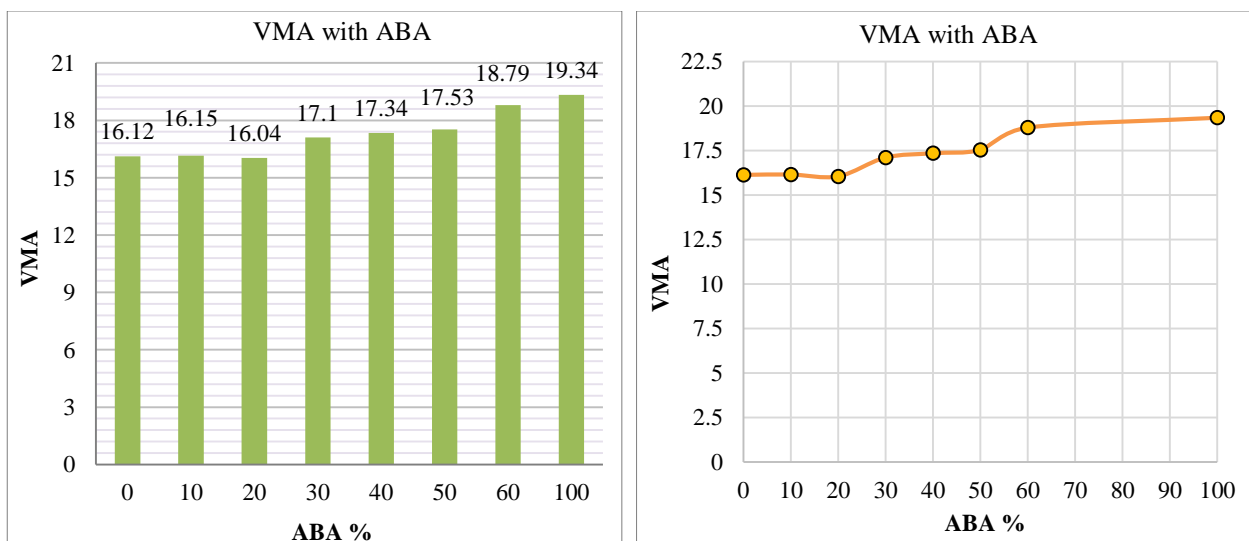


Figure 7. Relationship between VMA and ABA%

The void filled with asphalt (VFA) is the volume of the asphalt inside the asphalt mixture, and it is directly proportional to the density of the asphalt mix. The VFA is a very significant property because it is strongly related to the performance and durability of asphalt. The low percentage of the VFA leads to reducing the permanence of the asphalt concrete because it decreases the resistance to rutting under traffic loads and increases the bleeding of asphalt.

Figure 8 illustrates that the percentage of voids filled with asphalt in all the replacement ratios is acceptable and within the range according to [34], which is (70–85%). Besides that, VFA increases gradually with the increase in the ABA percentage, reaching the maximum with 100% of ABA replacement with 16.21% more than the control sample.

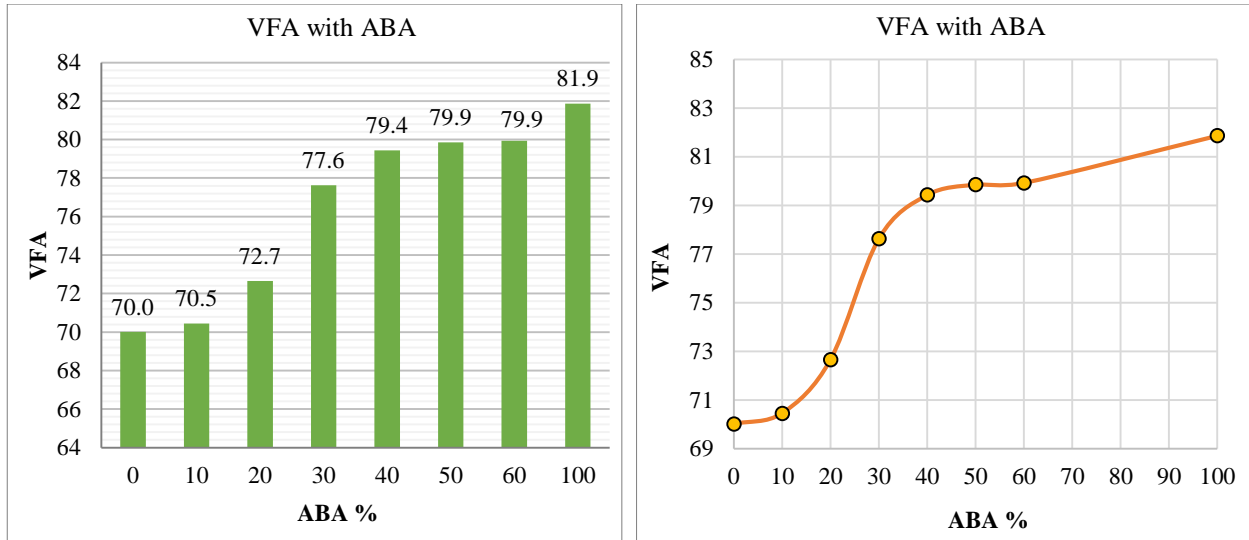


Figure 8. Relationship between VFA and ABA%

In general, a specific AV% is required in all asphalt mixtures to allow a slight drop due to the pressure of traffic under various conditions and according to the asphalt concrete design. Besides, the air voids allow asphalt to flow without causing cracking. On the other hand, the durability of asphalt pavement is strongly related to the air void content. A high volume of air voids content means high permeability in the mixture. That could be a reason for the undesired high drop in traffic loads. It can also create a passage for damaging liquids.

Figure 9 illustrates that there is a positive relationship between ABA% and VA%. The acceptable air void content is at replacement ratios of 10, 20, and 30% and equals 3.67, 3.77, and 3.82% respectively. The VA% of the 30% ABA replacement samples was higher by 4.08% than the VA% of the control sample. While the VA% percentages of the asphalt samples of ABA replacement are 40, 50, 60, and 100%, they are not acceptable according to standards.

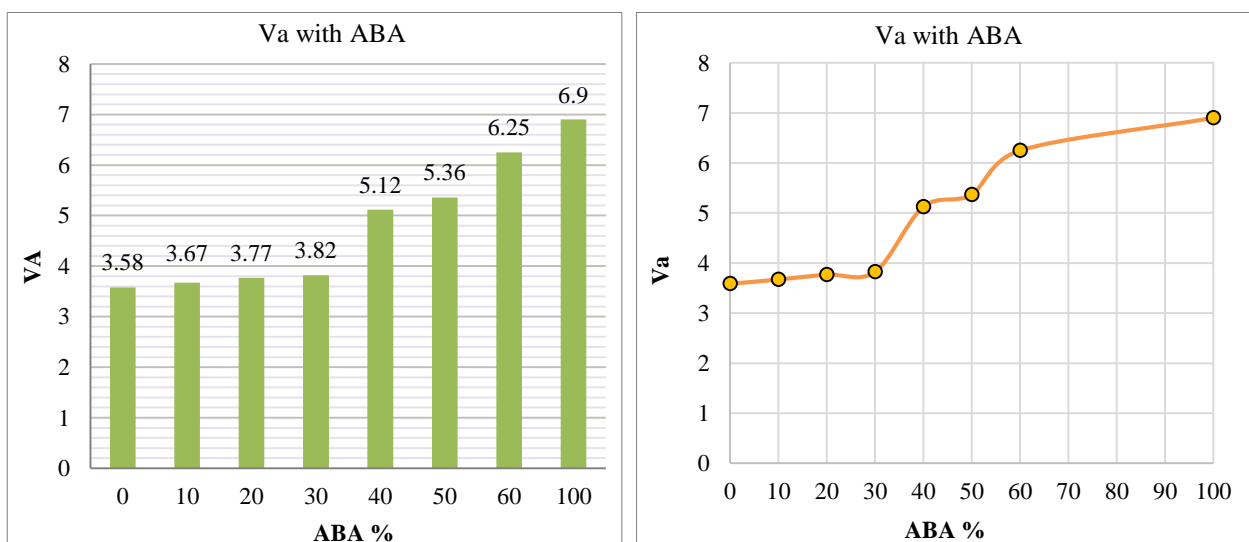


Figure 9. Relationship between VA and ABA%

The theoretical maximum specific gravity  $G_{mm}$  is equal to the specific gravity of the asphalt concrete mixture when compacted to a point of zero percent air voids. There are no standards for theoretical maximum specific gravity,



but it is used for the calculation of other properties such as air voids (VA) and field density. Typical values for Gmm range from approximately 2.4 to 2.7 depending on the aggregate specific gravity and asphalt binder content. From Figure 10, it can be observed that increasing the replacement ratios of ABA% content results in increasing the GMM values. Also, GMM values change between 2.455 and 2.465. The maximum GMM value is at 100% ABA replacement and the minimum GMM value was observed at 0% ABA replacement.

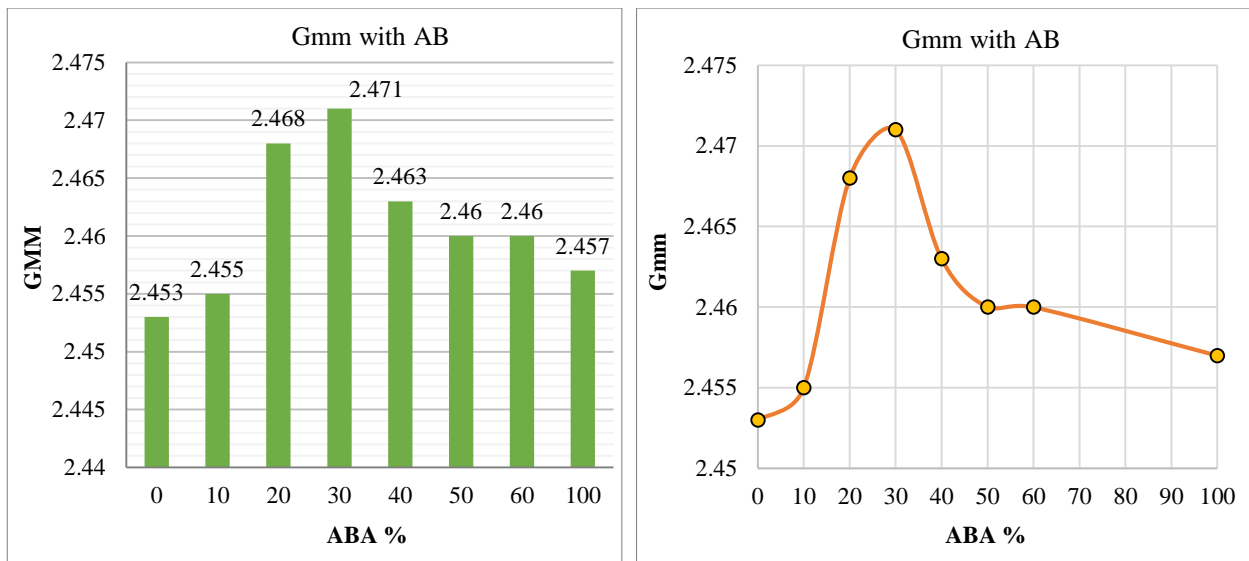


Figure 10. Relationship between GMM and ABA%

By summarizing the results of all the conducted experiments for the asphalt samples in Figure 11, it can be figured out that the 20% ABA replacement is the optimum percentage and it gives a significant enhancement to the asphalt mixture. The MS of 20% ABA replacement samples is the highest due to the positive effect of this material on the bond of the asphalt concrete. It can be noticed that increasing the percentage of ABA above 20% causes a gradual reduction in the MS values. This is because VA% is higher for the asphalt samples with ABA replacement of more than 20%.

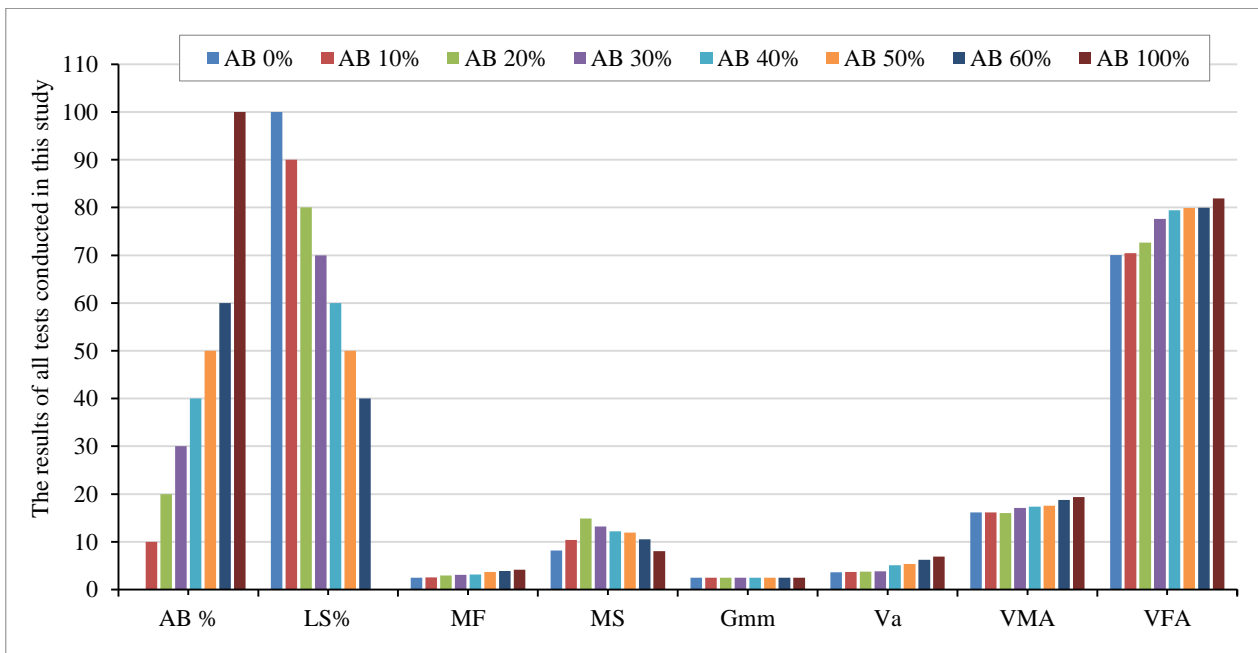


Figure 11. All the results of all the asphalt samples

In addition, all the results of the tests conducted on the asphalt samples show an overall improvement of the 20% ABA replacement within the standard range for design requirements [35] upon the other replacement percentages and the control samples. Table 6 lists all the test results (MS, MF, VFA, VA, VMA, and GMM) of 20% ABA replacement asphalt samples.

The Marshall stability (MS) for mixes using red mud and lime stone dust as a filler had 8.21 and 5.77% respectively higher Marshall stabilities than OPC mixes [16]. Using marble, granite and steel slag as fillers [17] shows a lower MS value than the control. Using date seed ash 100% as a filler increased the resistance of the mix by 36% compared with 100% conventional filler, while the mixture's stability value with 100% rice husk ash as a filler was 28% higher than that of the control sample [12]. In addition, using DSA and RHA as a filler reduces the air voids in the asphalt mix. Also, the replacement of conventional filler by RHA by 30% managed to increase Marshall Stability by 17.56% and decrease Marshall Flow by 18.53% in contrast with the HMA control sample [11]. When these findings are compared, it can be shown that utilizing ABA as a filler has significantly improved the mechanical characteristics of asphalt when compared to other filler materials, especially when using 20% ABA.

**Table 6. Properties of 20% replacement of ABA**

Properties	MS	MF	VMA	VFA	VA	GMM
Results	14.85	2.95	16.04	79.43	3.77	2.461
Specifications	>8	2-4	14	70-85	2-4	-

## 4. Conclusions

It can be concluded from the findings of this study that for all percentages except 100 percent, using ABA as a partial replacement for conventional filler increases the Marshall stability of asphalt concrete. This might be because fine ABA particles have a larger surface area, which strengthens the asphalt and improves its deformation resistance. Also, the development in mechanical properties can be attributed to the results that have emerged from previous studies, due to the percentage of calcium which results in more bonding that can be provided by bone powder.

- The MS and Gmm increase with the increase of ABA% till 20% then MS and Gmm test values decrease gradually due to the increase in the void ratio in the asphalt matrix.
- The highest improvement to asphalt mechanical properties achieved by using animal bone ash with 20%-30% replacement of filler. So 20% ABA has the highest MS value of 14.85 KN, which is 81% more than the control specimen.
- Increasing the animal bone percentage over 20% leads to a decrease in stability and increasing flow because of increasing air voids and voids in mineral aggregates, while the voids filled with asphalt are reduced. The voids in the asphalt mix are increased by increasing the ABA content above 20% because the ABA filler absorption is lower than the limestone filler, so the asphalt mix can be less homogenous by using a high percentage of ABA filler.
- Utilizing ABA in construction, such as in asphalt concrete, can help to decrease the environmental issues related to waste disposal while also reducing the consumption of traditional highway materials, lowering the costs of asphalt pavement.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, A.T. and Y.N.; methodology, W.A. and Y.N.; software, Y.N.; validation, Y.N., A.T. and W.A.; formal analysis, W.A.; investigation, A.T.; resources, Y.N.; data curation, Y.N.; writing—original draft preparation, A.T.; writing—review and editing, W.A.; visualization, A.T.; supervision, Y.N.; project administration, W.A.; funding acquisition, W.A. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

Part of the data for this study is available in this article and the other is available on request from the corresponding author.

### 5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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