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OPTIMUM BONE ASH FILLER IN HOT MIX ASPHALT

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ABSTRACT
Engineers and scientists are frequently investigating various techniques to enhance the performance of the road pavements. Supplementary materials or additives are being evaluated for use in pavement materials to enhance the performance and quality of the pavement structure, in order to provide a durable, impermeable and safe road surface for the road users. This propelled the research for a replacement of the conventional Stone Dust (SD) with Bone Ash (BA) in Hot Mix Asphalt (HMA). The Optimum Bitumen Content (OBC) was determined for all the sample mixes by Marshall mix design. The SD was replaced with BA in the following order 0% (control), 20%, 40%, 60%, 80% and 100% at OBC of 6%. Laboratory testing and experimental results indicated higher stability value, lower flow value at optimum BA content of 20%. The Void in the Mix (VIM), Voids filled with Bitumen (VFB) all lie well within range thus sati sfying the code (NGSRB, 2016) specification. Generally, there was improvement in the Marshall and Mechanical properties of Asphalt concrete mixtures when BA was used. It can be concluded that optimum bone ash content of 20% at optimum bitumen content of 6% is recommended for a good HMA.
Keywords: *Bone Ash, Hot Mix Asphalt, Marshall Mix Method, Stone Dust.*

INTRODUCTION
The early use of asphalt for road and street construction began in the late 1800s and grew rapidly with the emerging automobile industry. Since that time, asphalt technology has made strides such that today the equipment, techniques and materials used to build asphalt pavement structures are highly sophisticated (Hassan *et al*., 2011).

With the fast economic growth and increasing consumption, a large amount of waste materials are generated in various sectors worldwide. The large amount of waste (such as scrap tires, glass, blast furnace slag, and steel slag, plastics, and construction and demolition wastes, agro wastes) continuously accumulating in stockpiles and landfills throughout the world are constituting disposal problems which are financially and economically problematic. Serious efforts and commitment is required towards the proper disposal of these wastes. One tangible solution is in the recycling and use of these materials in construction of highways and pavement design (Wu *et al*., 2003).

Many studies have been conducted by exploiting different types of waste materials as stabilizing agents or fiber content, filler and aggregate materials in Stone Mastic Asphalt mixture in flexible pavement. Divergent fibers and polymers (such as rubbers, polymers, artificial silica, steel slag, ceramic waste, coal fly ash, lime stone, rejected ceramic raw materials, cellulose fiber, synthetic fiber, polypropylene fiber, polyester fibers etc.) have been used as stabilizers in Stone Mastic Asphalt mix (Putman and Amirkhanian, 2004).

The modification of HMA mixes for enhanced performance is not a new concept. These modifications are increasingly being sought from waste materials to promote sustainable development and economy. Several researches have been carried out to integrate waste materials into HMA. These include scrap rubber, waste glass, boiler ash, incinerator residue, coal-plant refuse (Kandhal, 1992), and steel slag (Huang *et al*., 2007).

An important avenue of HMA modification involves the use of mineral fillers. Mineral filler is simply a mineral material that is not reactive to the other components of the asphalt mixture, finely divided, at least 65% passing the sieve opening of 0.075 mm square mesh. Experience has proven that the filler plays a vital role in the behavior of asphalt mixtures. Mineral fillers should be easily pulverized and free of cemented lumps, mud-balls, and organic materials (Kandhal, 1992). Excess quantity of filler tends to increase stability, brittleness and natural tendency to cracking. Deficiency of fillers tends to increase void content, lower stability, and soften the mix (Csanyi, 1962).

Bone Ash is the whitish matter obtained from animal bones calcined at very high temperatures and milled into very fine particle sizes. From several literatures consulted and from the XRF, the major oxide constituent in Bone Ash is Calcium Oxide (CaO) as can be seen in Table 2. Ayininuola and Shogunro (2013) revealed that bone ash calcined at a temperature of 1100°C contains the following oxides: CaO (55.25%), P_2O_5 (41.65%), MgO (1.40%), CO_2 (0.43%), SiO_2 (0.09%), Fe_2O (0.08%) and Al_2O_3 (0.06%). Also, calcium oxide composition of bone ash is reasonably high (ranges between 30 – 50%). This is reasonably close to the calcium oxide content of cement (60 – 67%) and way beyond that found in Stone Dust (SD) which are the conventional mineral fillers used in Hot Mix Asphalt. Haldar and Das, (2012) stated that the oxide composition of stone dust is given as CaO (2.89%), P_2O_5 (41.65%), MgO (1.54%), CO_2 (0.43%), SiO_2 (72.7%), Fe_2O (4.1%), Na_2O_3 (2.53%) and Al_2O_3 (10.91%). Stone dust is very rich in Silicon Oxide (SiO_2). Large amount of SiO_2 can cause stripping of HMA pavements because silica reduces the bond strength between the aggregate and binder (Yasreem *et al.*, 2011). Bone Ash would serve as a suitable replacement to stone dust because it will augment the lack of Calcium Oxide in the stone dust, while ensuring a cleaner environment and turning waste into wealth.

This work is aimed at evaluating the suitability of bone ash as mineral filler in HMA. The properties of constituent materials of the HMA were determined in order to ascertain its use in road construction. The proportion and gradation of aggregates to be used for the mix design was determined. The optimum bitumen content of the mix was determined. The chemical composition of the bone ash was determined to establish the chemical analysis of the material. Finally, the strength properties of the mix prepared with stone dust replaced with bone ash using Marshall Method of mix design were determined.

MATERIALS AND METHOD

Materials

The materials used for this study are bitumen, aggregates (coarse and fine), and filler (stone dust and bone ash). The coarse and fine aggregates used in the mix design were obtained from a quarry site in Zaria. Their specific gravities are 2.63 and 2.65 respectively. Penetration grade bitumen of 60/70 obtained from the Ministry of Works, Kaduna State, was used in this investigation to prepare HMA mixes after it conformed to NGSRB (2016) specification. The BA used was mainly cow bone ribs as obtained from a dump site Zaria environ, Kaduna State.

METHOD

The method used in this work is outlined below.

Test of aggregates

The following tests were conducted on the aggregates. Impact and Crushing values, sieve analysis, specific gravity, flakiness and elongation index.

The Aggregate Crushing Value (ACV) gives relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. The aggregate impact value test provides a relative measure of the resistance of an aggregate to sudden shock or impact. These tests were carried out on the coarse aggregates in accordance with BS 812 (1990) at the concrete technology laboratory, Ahmadu Bello University, Zaria.

Test on bitumen

The physical properties' tests carried out on the bitumen are penetration, ductility, specific gravity, solubility and softening point test. These tests were carried out at the Highway and Transportation Laboratory, Department of Civil Engineering, Ahmadu Bello University, Zaria in accordance to BS3690-1 (1989).

Test on mineral filler

Chemical composition using X-ray fluorescence, sieve analysis and specific gravity.

Marshal stability test

Marshal stability tests on asphalt briquettes in accordance to ASTM D 1559 (1986) was conducted to determine the optimum binder content and optimum bone ash replacement. The average of the sum of binder contents at maximum stability, maximum bulk density and 5.5% air void in total mix was used as the optimum bitumen content.

RESULTS AND DISCUSSION

Test on Bone Ash

The sieve analysis of the bone ash was carried out in the Laboratory and the result is as presented in Table 1. About 75% of the BA material passed through the 0.075 mm sieve and as such, it is very suitable for use as mineral filler in the HMA.

Chemical analysis was carried out to determine the elemental composition of the Bone Ash. About 3grams of Bone Ash was analyzed. The concentration of elements in the bone ash sample is given in the Table 2. The major oxide constituent in bone ash is Calcium Oxide (CaO). CaO is a very vital ingredient in mineral filler. It is very influential in asphalt performance. Increase in the value of CaO, SO_3 and LOI increases the complex shear modulus and stiffness of mastic asphalt.

Table 1: Sieve analysis of filler (bone ash/investigation)

Sieve size(mm)	**Mass retained (g)**	**Percentage retained (%)**	**Percentage passing (%)**
150 μm	0	0	100
75 μm	27	13.5	86.5
Pan	173	86.5	0
Total	**200**	**100**	**0**

Table 2: Oxide composition of bone ash

Compound	**Concentration (%)**
CaO	54.14
SiO_2	0.819
Al_2O_3	0
Fe_2O_3	0.00995
P_2O_5	38.03
MgO	1.4
CO_2	0.43

Bitumen Tests

The test results obtained from the binder are compared with the Nigerian General Specification for Road and Bridges (NGSRB, 2016). The results obtained were in line with the standards specified in the code thus, the Bitumen is suitable for the HMA design. Table 3 gives a highlight of the test results obtained. From Table 3, the bitumen used in this research meets up to standard specified in the code and is therefore suitable for use in HMA.

Test on Aggregates

Table 4 indicates the result of test of physical properties of the Aggregates. These results are in accordance with the specifications in the code. This indicates its suitability for use in HMA.

Gradation of Aggregates

Sieve analysis was conducted to determine the particle size distribution in accordance with BS 812 (1990). This entails the procedure for separating a sample of aggregates into fractions, each consisting of particles of the same size. The Figures 1 and 2 depicts the particle size distribution curve for the coarse aggregate and fine aggregate respectively. Each fraction contains particle between specific limits. This indicates its suitability to be used in the HMA.

Table 3: Comparison of bitumen test results with standard specifications

Test	**Unit**	**Test result**	**Code specification (NGSRB, 2016)**
Ductility at 25^{o}C	cm	108	≥100
Specific Gravity	g/cm^3	1.03	1.01 – 1.06
Penetration at 25^{o}C	mm	68	60/70
Softening Point	^{0}C	49.3^{o}C	48 – 56
Solubility	%	99	99

Table 4: Physical Properties of aggregates test results and standard specifications

Test	**Test result**	**Test result**	**Code specification (NGSRB, 2016)**
Aggregate Crushing Value	%	23.66%	< 30
Aggregate Impact Value	%	23.10%	< 30
Specific gravity (Coarse)		2.63	2.6 – 2.9
Specific gravity (Fines)		2.65	2.6 – 2.9
Specific gravity (SD)		2.65	2.6 – 2.9
Specific gravity (BA)		2.95	2.95
Flakiness index	%	10.62	< 35
Elongation index	%	19.9	< 35

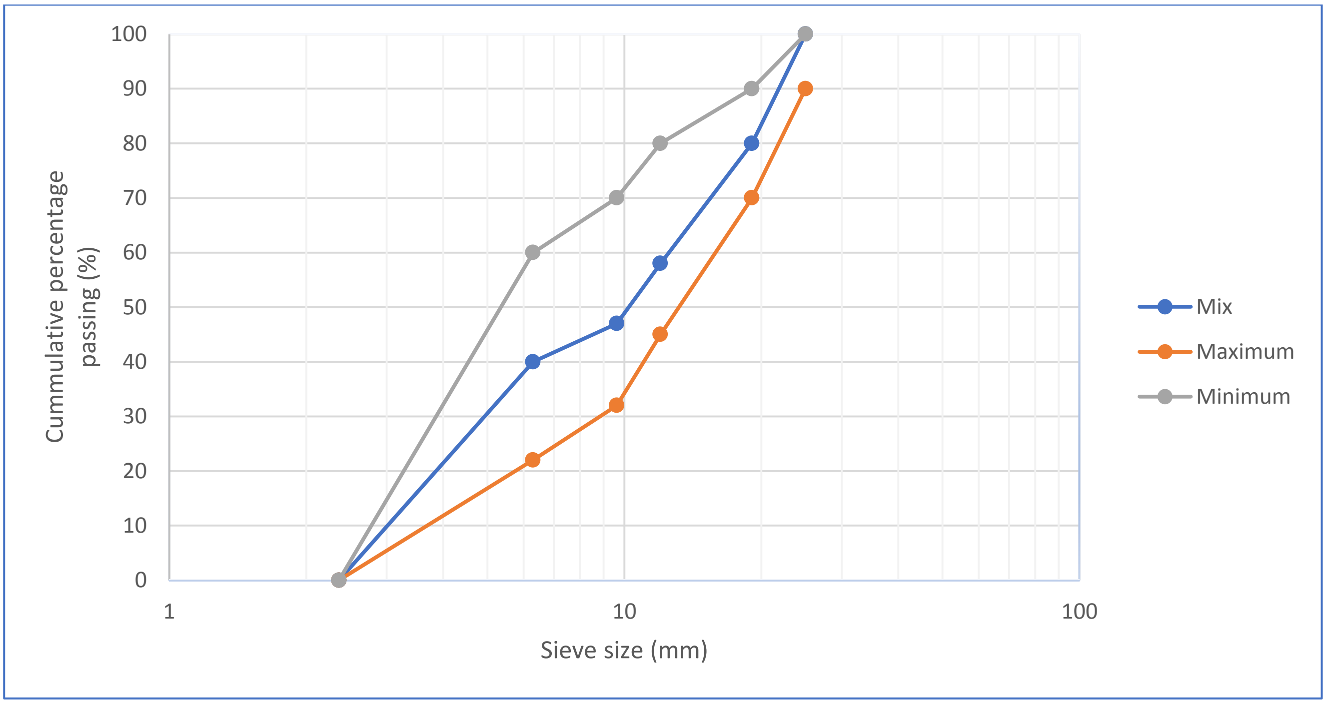

Figure 1: Particle size distribution curve for coarse aggregate

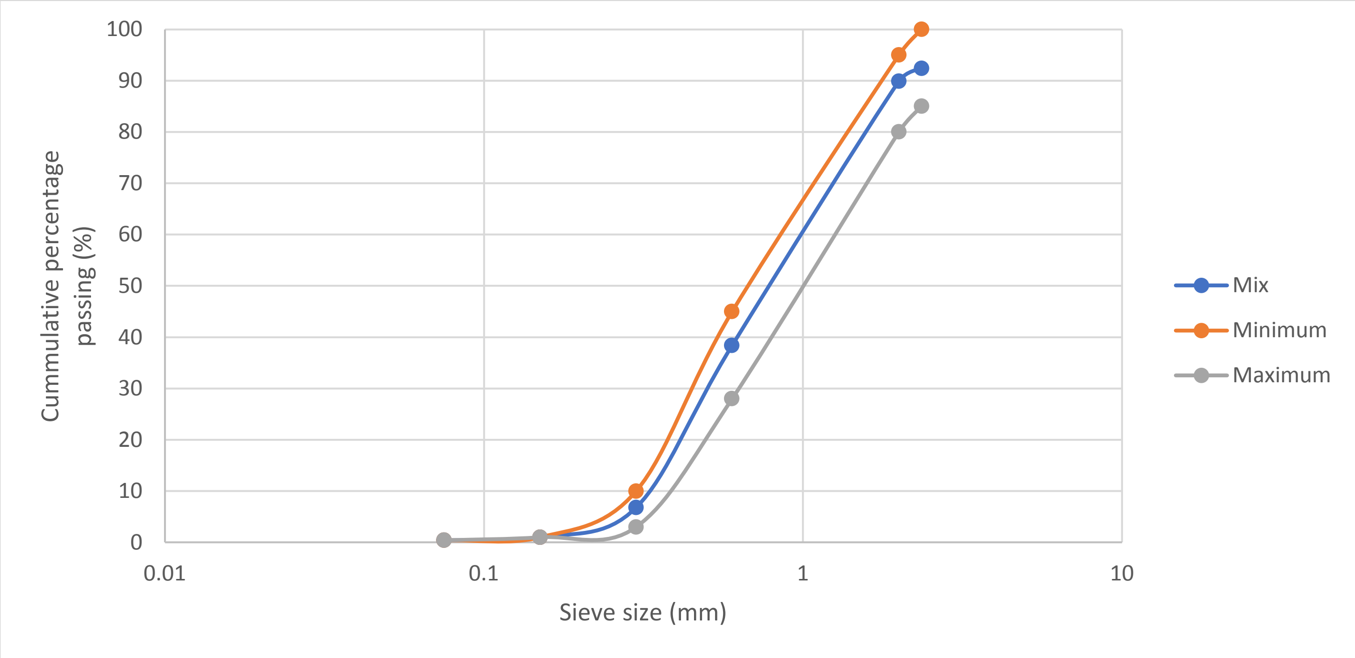

Figure 2: Particle size distribution curve for fine aggregate

Marshall Properties of the Control Samples Stability

The stability of asphalt indicates the maximum load the compacted specimen of asphalt can carry at standard test temperature of 60°C with loading applied at a constant rate of about 50.8 mm/min. Figure 3 depicts the stability value for the various bitumen contents employed herein. The maximum stability of 5.63 kN was obtained at a bitumen content of 5.5%.This value was used in determining the optimum bitumen content of the mix.

Flow

Jendia, (2000) described flow as the total amount of deformation that occurs at maximum load. Figure 4 depicts the flow value for the various bitumen contents employed herein. From Figure 4, the maximum flow was obtained at a bitumen content of 7%. The bitumen content of 7% was used in determining the optimum bitumen content of the mix.

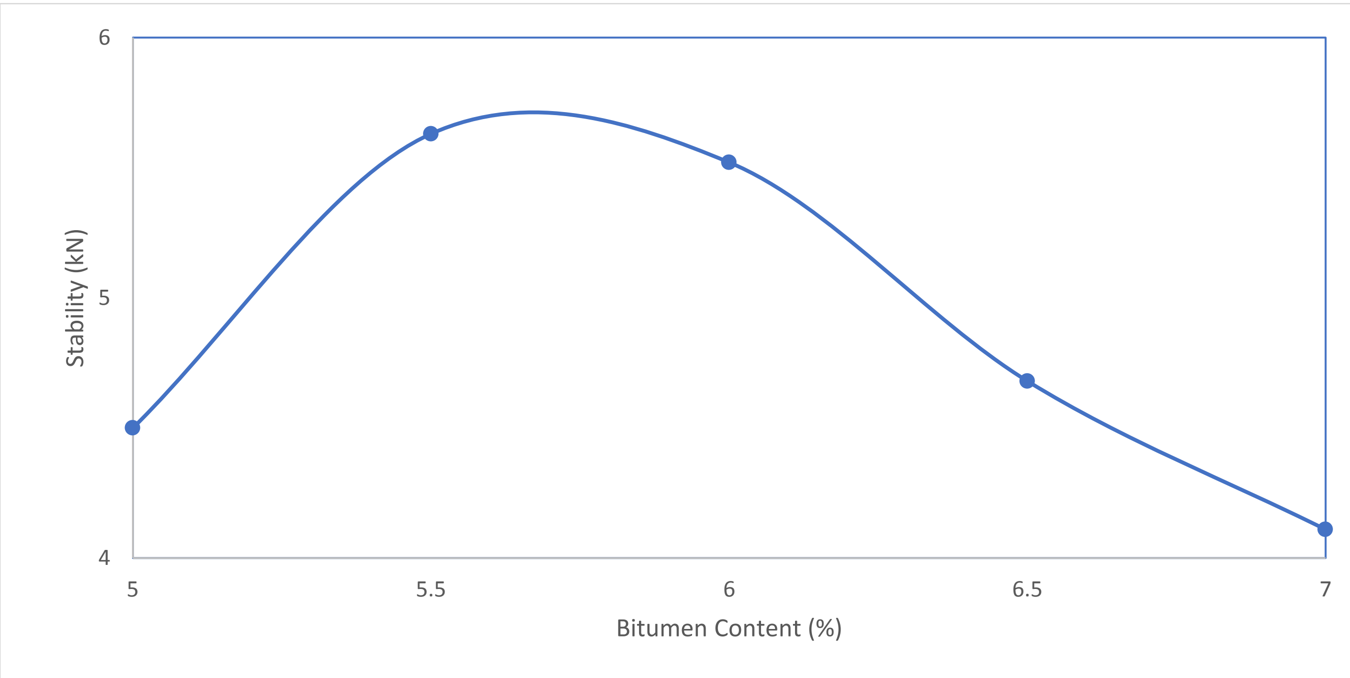

Figure 3: Relationship of Marshall Stability to bitumen content

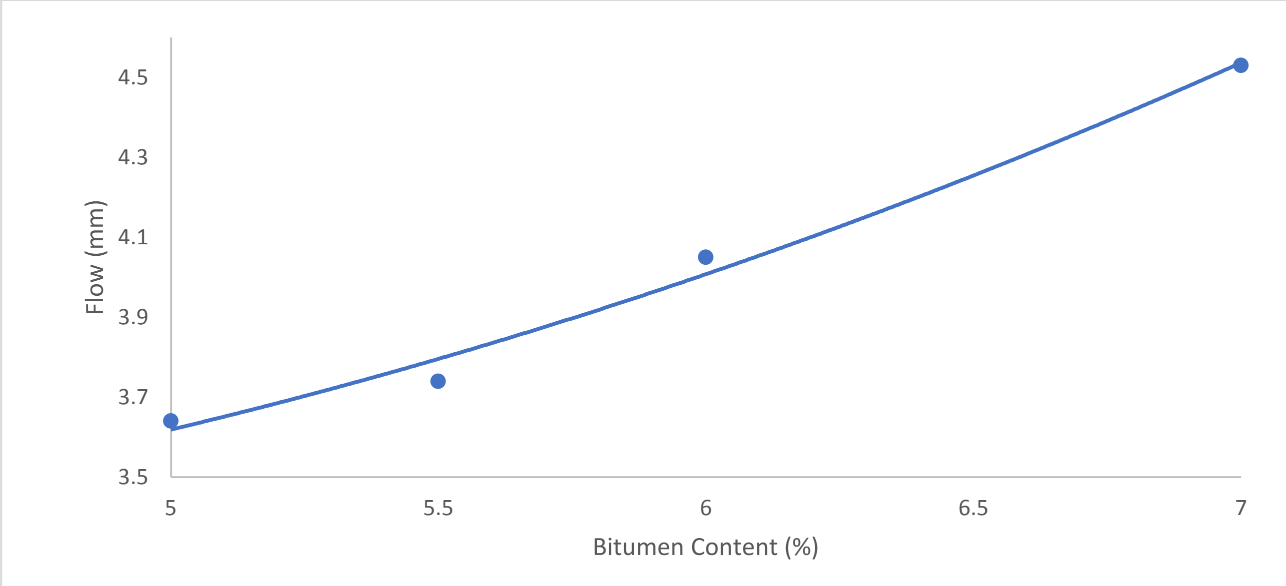

Figure 4: Relationship of flow (mm) to bitumen content (%)

Bulk Density
Bulk density of the asphalt mix is defined as the compacted density of the mix. Figure 5 depicts the bulk density value for the various bitumen contents employed herein. From Figure 5, the point of maximum bulk density was at 2.266 g/cm^3, obtained at 6% bitumen content. The bitumen content of 6% was used in determining the optimum bitumen content of the mix.

Voids in Mineral Aggregates (VMA)
This is defined as the percentage of void spaces between the granular particles in the compacted paving mixture, including the air voids and the volume occupied by the effective asphalt content (Hoel and Garber, 2010). Figure 6 shows the VMA at various bitumen contents.

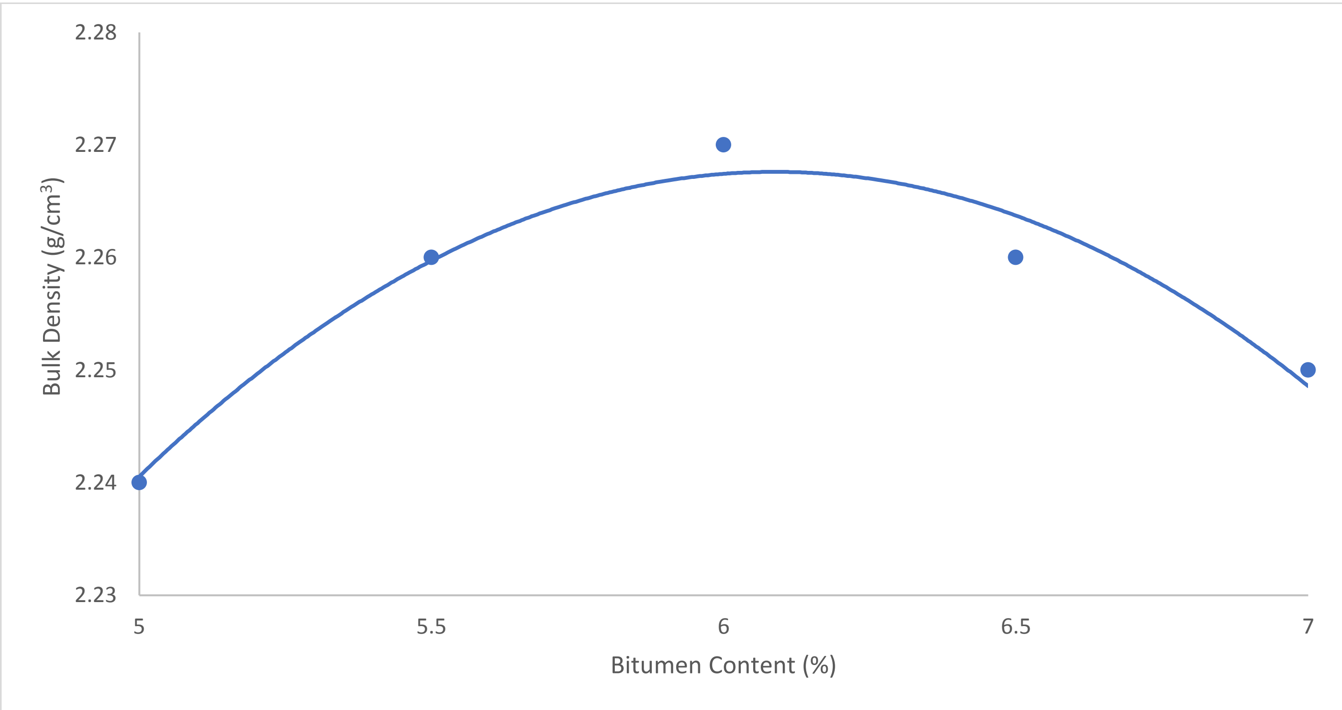

Figure 5: Relationship of bulk density to bitumen content

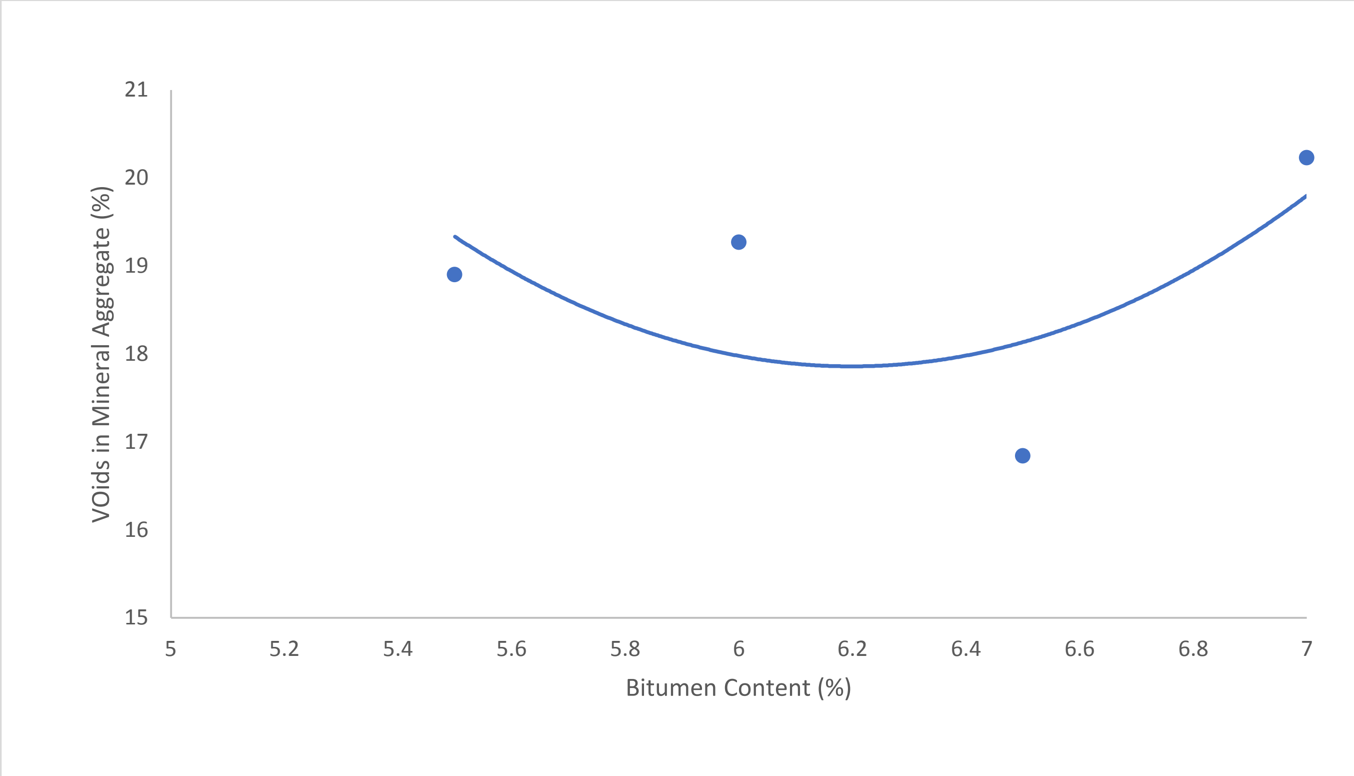

Figure 6: Relationship of Void in the Mineral Aggregates (VMA) to bitumen content

Voids in the Mix

Figure 7 depicts the voids in the mix value for the various bitumen contents employed herein. From Figure 7, it can be observed that there's a decline in voids in the mix as bitumen content increases. This is because more voids are filled with increasing bitumen content.

Voids filled with Bitumen (VFB)

Figure 8 shows the result of voids filled with bitumen of various bitumen contents as evaluated. From Figure 8, VFB increases with increasing bitumen content because more voids are filled with bitumen with increasing bitumen content.

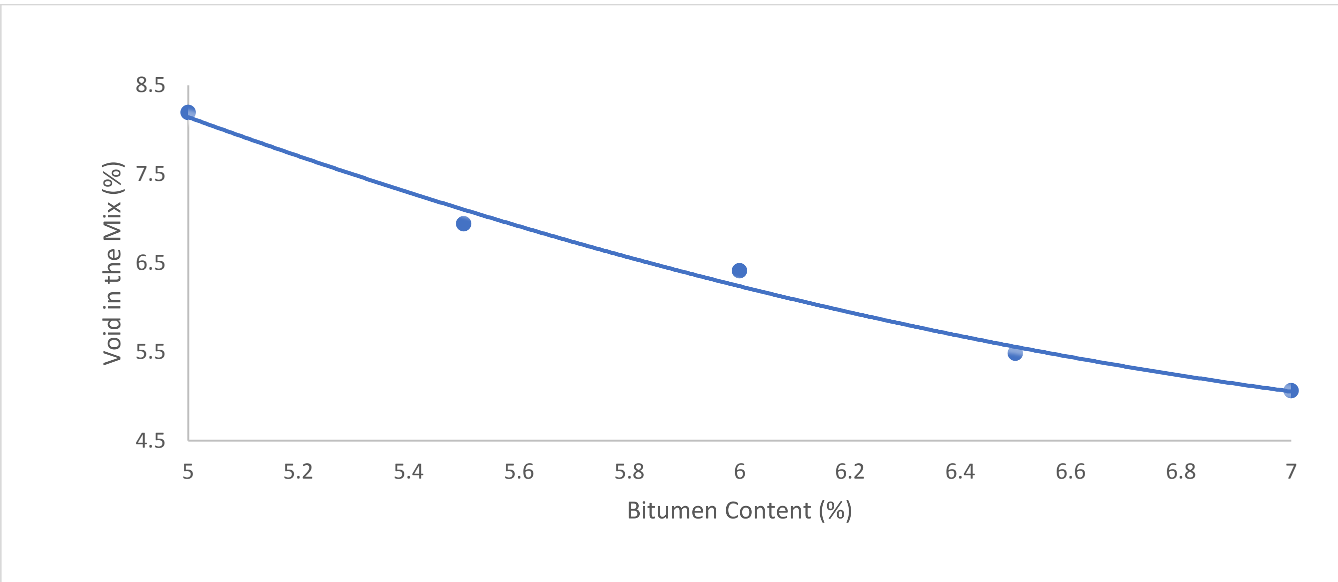

Figure 7: Relationship of Voids in the Mix to bitumen content

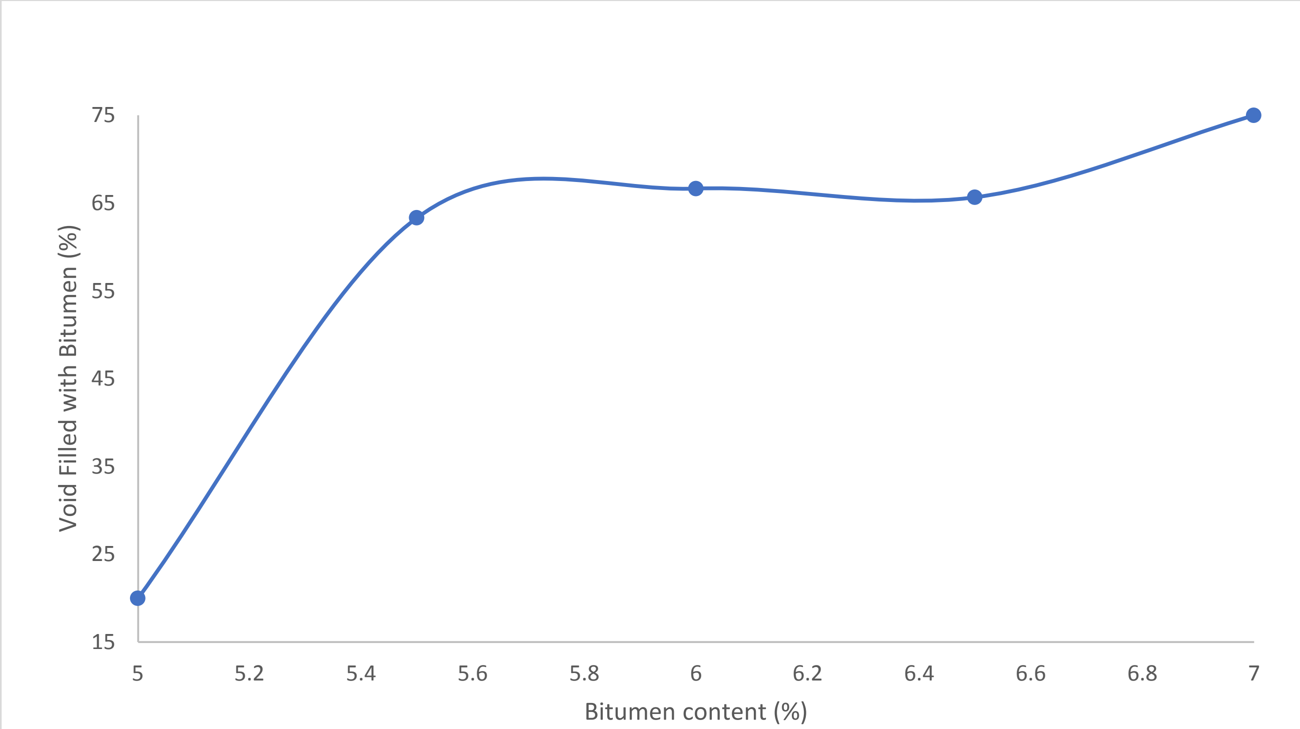

Figure 8: Relationship of Voids Filled with Bitumen to bitumen content

Optimum Bitumen Content (OBC)

From Figures 3 – 8, the average of sum of the bitumen content for maximum stability, maximum bulk density and percent voids within the limits specified (average of the limits) gives the Optimum Bitumen Content (OBC). From Figures 3, 5 and 7, the values of bitumen contents at maximum bulk density, maximum stability and median of air voids were 6.0%, 5.5% and 6.8% respectively. The average values of these values were obtained to be 6.0% which serves as the Optimum Bitumen Content.

Marshall Properties of the Investigated Samples

Stability

There was an initial increase in the stability with increasing BA content. This stability value reduces with higher BA content as seen in Figure 9. This is as a result of lower contact points between the aggregates. 20% bone ash content gave the optimum stability value of 8.76 kN which lies with the specification (Not less than 3.5 kN) stated in the NGSRB, (2016) specifications.

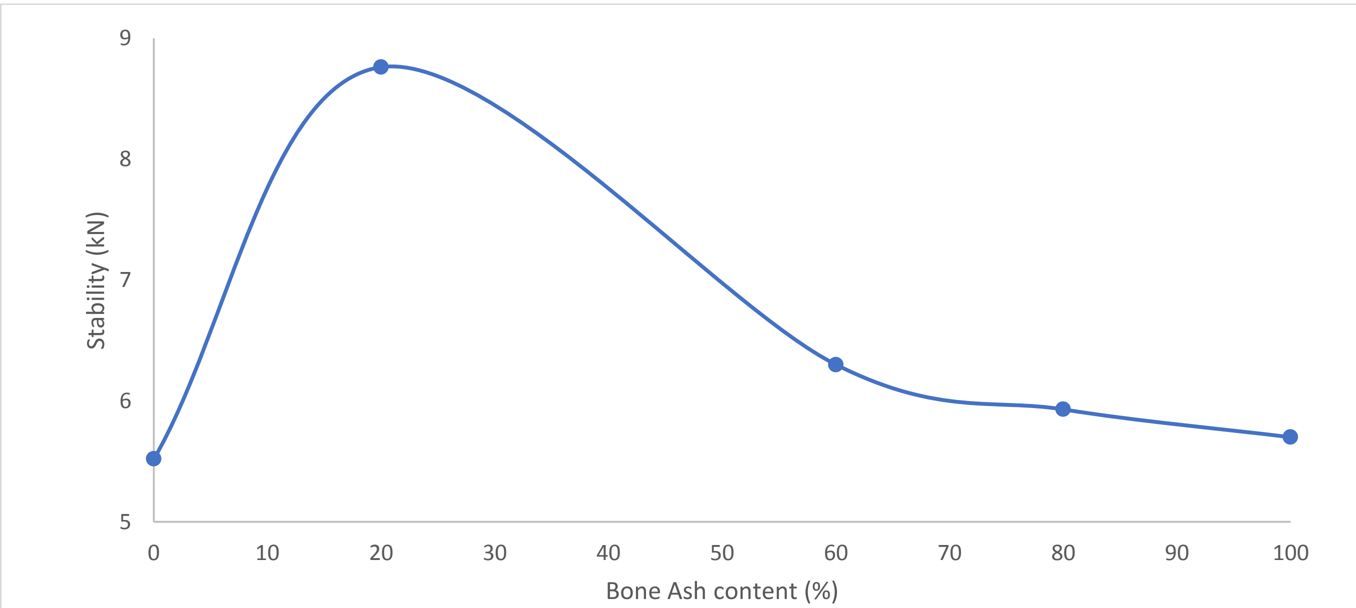

Figure 9: Relationship of bone ash content to stability

Flow

The Figure 10 gives a graphical relationship between the flow and bone ash content. The least flow of 3.4 mm is obtained at a bone ash content of 20%. This flow value lies with the specification (2 mm – 6 mm) stated in the NGSRB, (2016) specifications.

Bulk Density

Figure 11 indicates an initial increase in the bulk density at 20% bone ash content. Subsequently, there is a decline in the bulk density with increasing bone ash content. The optimum percentage of bone ash for increased density is 20% as depicted in Figure 11. Thus higher bone ash filler content will yield a lower density.

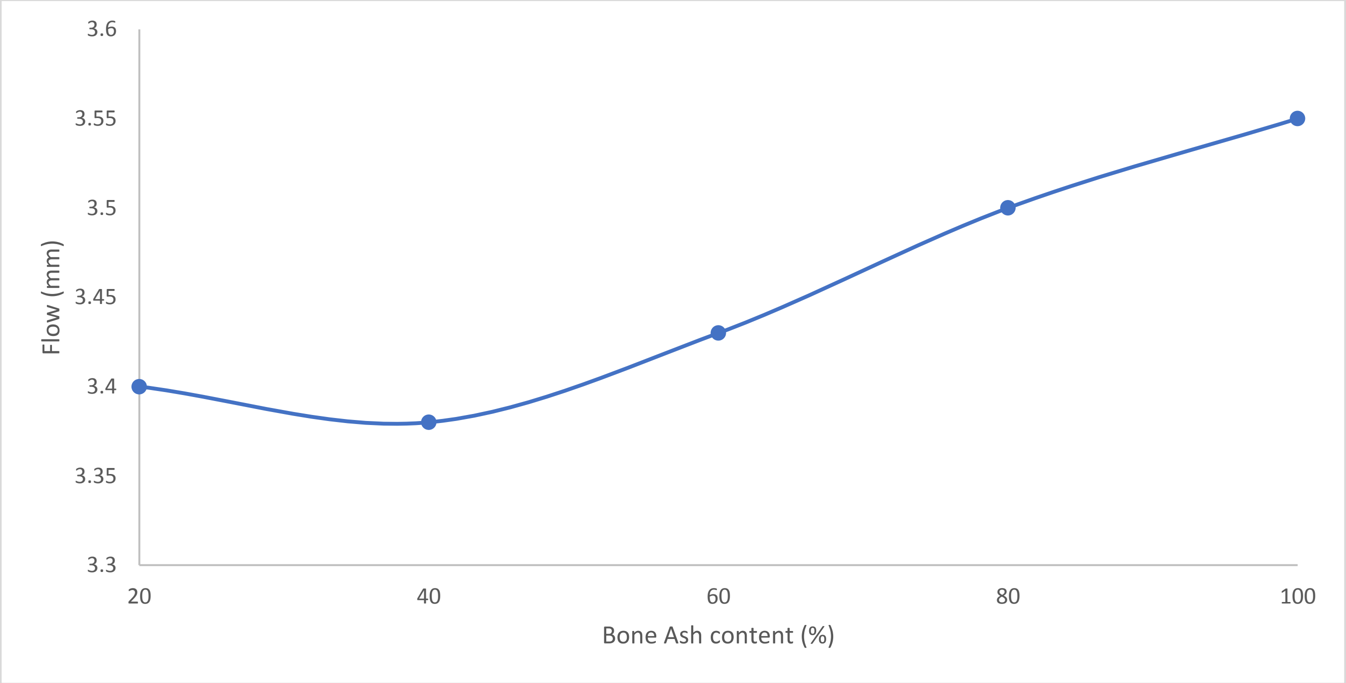

Figure 10: Relationship of bone ash to flow

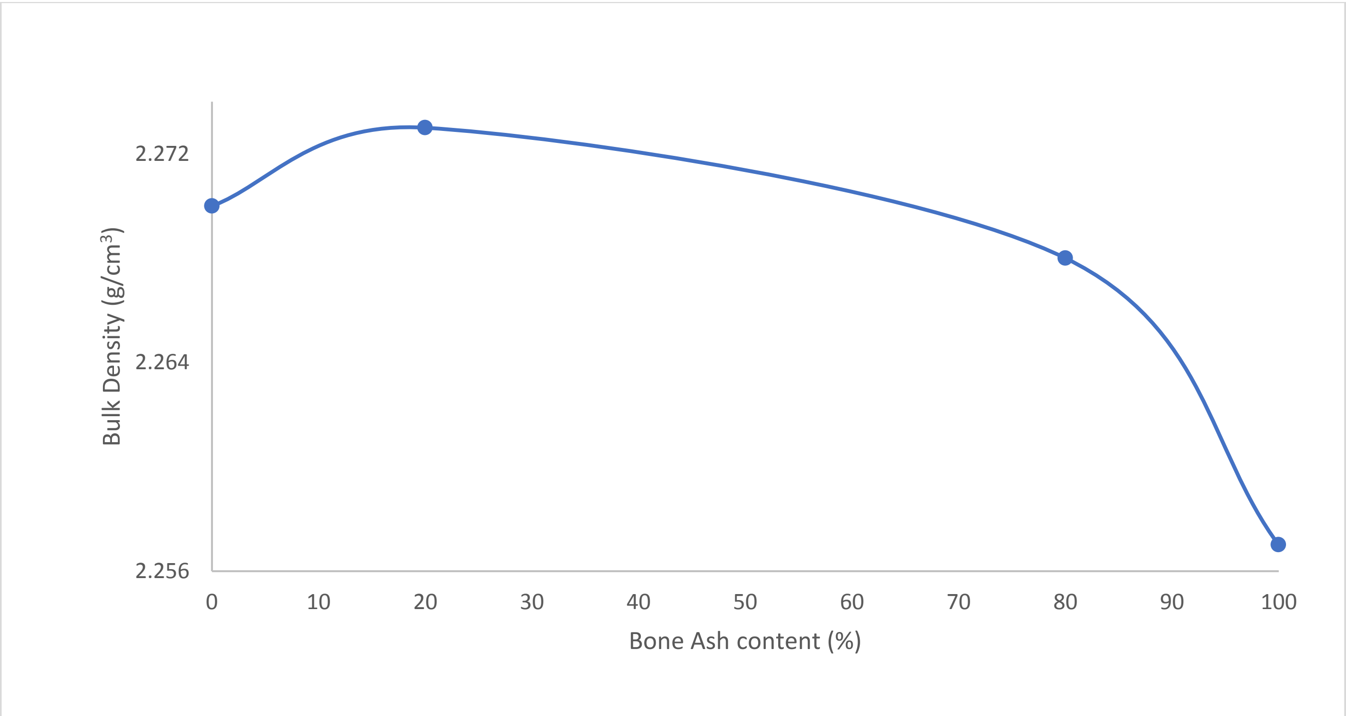

Figure 11: Relationship of bulk density to bone ash content

Voids Filled with Bitumen (VFB)

The voids filled with bitumen were all within range (65 – 72%) as specified in the NGSRB (2016) from 20% to 60% bone ash replacement as shown in Figure 12. At 80% and 100% replacement, the VFB was out of range of what the code specifies. From the VFB values that fall within range, the 20% bone ash replacement gives the highest value of VFB at 67.65% against a VFB value of 66.66% at 0% bone ash replacement.

Voids in Total Mix

It can be observed from Figure 13 that the percentage of voids in the total mix increased with increasing bone ash filler content. More voids are created with higher bone ash content, thus increasing the volume of voids in the total mix. At bone ash contents of 20% to 60%, the voids in the total mix lie within the specified range of 3 – 8% specified in the NGSRB (2016). However, there is a sharp decline in the amount of air voids at 100 percent replacement. The relationship of the void in total mix to various bone ash content is shown in Figure 13.

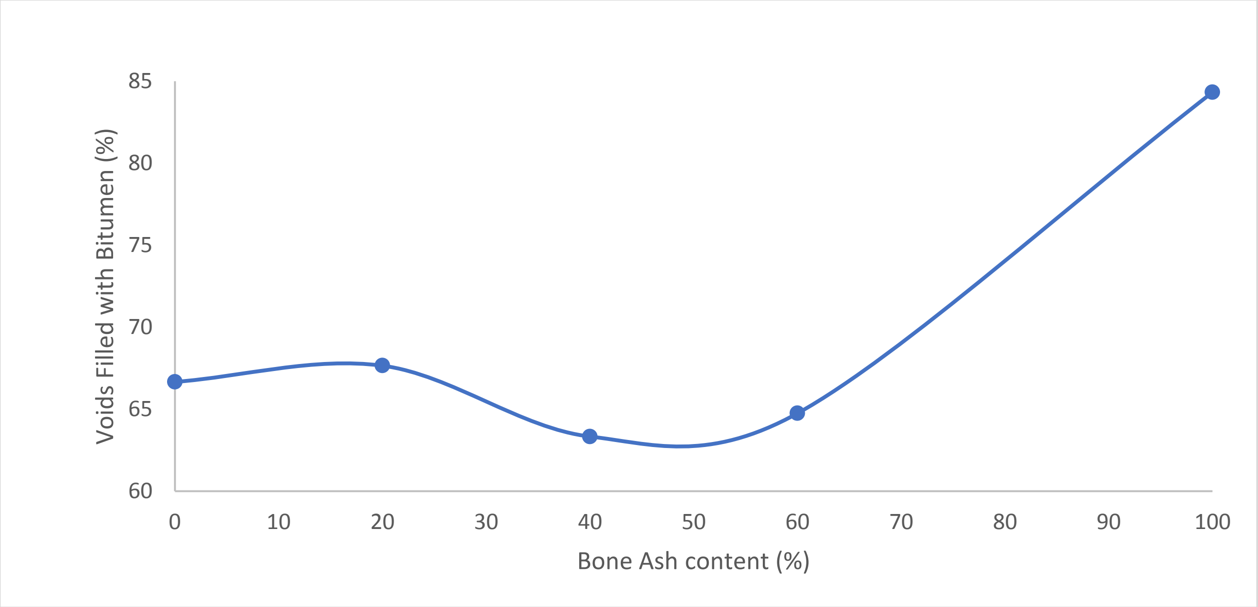

Figure 12: Relationship of bone ash to voids filled with bitumen

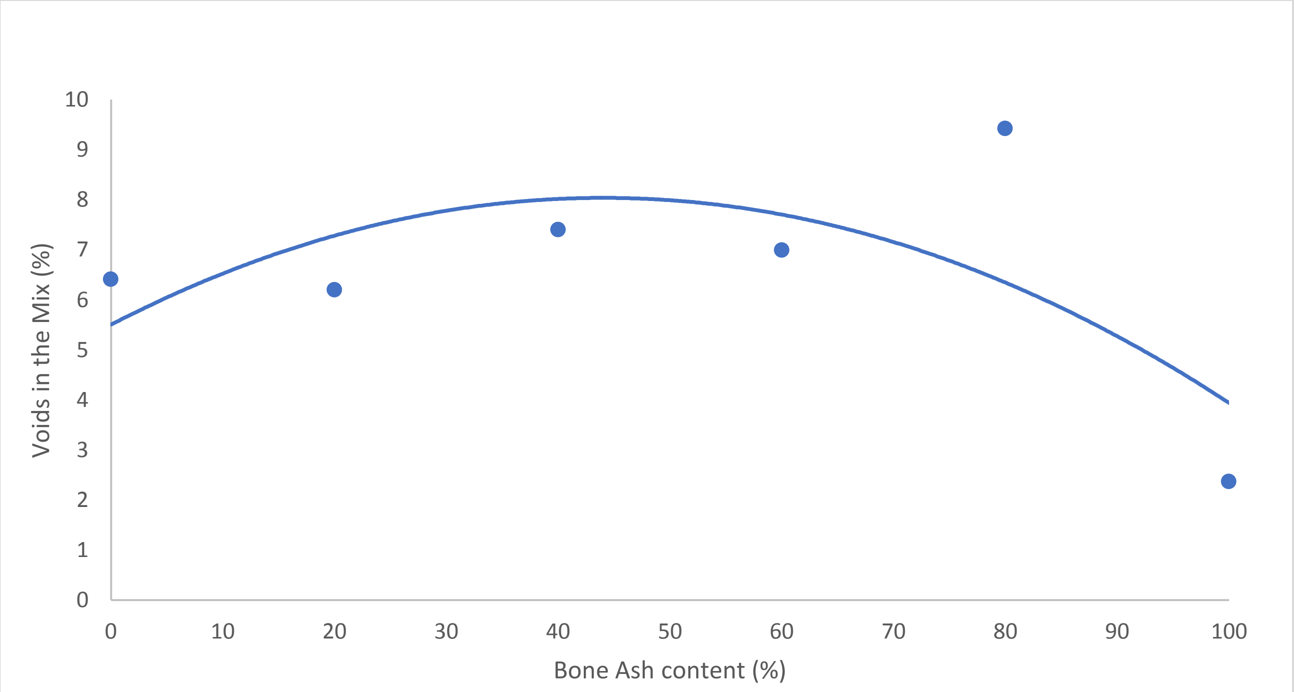

Figure 13: Relationship of bone ash to voids in total mix

From the relationships illustrated in Figures 9 – 13, it can be observed that all the Marshall Stability values for the various bone ash contents evaluated satisfy the specifications (that is, not less than 3 kN) stated in the NGSRB (2016). The optimum stability value obtained was 8.76 kN at 20% bone ash content. Furthermore, at 20% bone ash content, the value of flow, voids in mineral aggregate, voids in total mixture, voids filled with bitumen are given as 3.4 mm, 19.17%, 6.2% and 67.65% respectively. All these are within the limits specified by the code. Table 5 gives a comparison between the optimum bone ash content and specification range stipulated in the NGSRB, (2016) code.

Table 5: Comparison of marshall properties of optimum bone ash content and the NGSRB (2016) specification

Property	**Optimum bone ash content (20%)**	**Optimum bitumen content**	**NGSRB (2016)**	**Remark**
Stability (kN)	8.76	5.52 kN	Not less than 3.5kN	Ok
Flow (mm)	3.4	4.06 mm	2 – 6	Ok
Voids in Total Mix (%)	6.2	6.41%	3 – 8	Ok
Voids Filled with bitumen	67.65	66.66%	65 – 72	Ok

CONCLUSIONS

From this work, the following can be concluded:

All the Marshall values for the control and investigated samples lie well within the range specified by NGSRB (2016). This indicates that the constituent materials are suitable to be used in HMA and thereby the OBC can be determined.

The optimum bitumen content for the control samples was obtained to be 6% which lie within the range specified by NGSRB (2016).

The chemical composition of the bone ash shows that it contains about 55% lime (CaO) content thereby making it suitable for use as mineral filler in HMA as specified by NGSRB (2016).

The optimum bone ash content to partially replace stone dust in asphalt concrete mix is found to be 20% of the total SD. This indicates the suitability for use of BA as mineral filler in HMA at an optimal value of 20% content by weight of SD.

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