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APPLICATION OF SAWDUST ASH AS FILLER MATERIAL IN ASPHALT CONCRETE PRODUCTION

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Abstract: Continuous generation of wastes from industrial by-products and agricultural residue creates severe environmental trouble in terms of treatment and disposal in Ethiopia. Utilization of by-products and residue in construction work is an excellent alternative solution in reducing disposal problems. In this research, the application of sawdust ash in asphalt concrete production is investigated as filler material. Physical and chemical tests were investigated for Saw Dust Ash (SDA). Asphalt specimen prepared using basaltic stone dust without sawdust as filler used as a control material. The SDA was partially replaced with 3%, 6%, 9%, and 12% by weight of basaltic filler. The performance evaluation of mixtures was investigated using indirect tensile fatigue, indirect tensile strength, and permanent deformation tests. The results indicated that the application of SDA as a mineral filler improved the fatigue life and permanent deformation of asphalt concrete at different temperatures. It was also determined that the mixtures with SDA showed lower moisture susceptibility than basaltic filler. The finding indicated that the optimum value of SDA could be partially replaced the conventional filler is 12% in asphalt concrete production.

Keywords: sawdust ash, disposal problem, partial replacement, fatigue life, permanent deformation

1. INTRODUCTION

Locally available and easily accessible materials are always economically realistic in the asphalt concrete production of road construction. The industrial by-product waste disposal is selected as a filler material in asphalt concrete production (1). The pozzolanic properties of filler material convey technical merits to the resulting asphalt concrete with a large amount of cement partial replacement (2).

The application of these materials brings environmental and economic benefits. Waste material reprocessing products are the current method of solving waste problems (3). Recycling is a process to change waste materials into new products to prevent hazards associated with waste, reduces the consumption of fresh raw materials, and it also reduces greenhouse gas emissions arising from the conventional method of disposing of such wastes (4). A filler material plays a significant role in the engineering properties of bituminous materials. Conventionally, stone dust, cement, and lime are used as filler materials (5).

Filler material includes those materials which pass 75μm (No. 200) BS sieve. The most important properties of filler materials are the geometry and composition of the material. Filler geometry can be recognized by size, shape, texture, and angularity. Bitumen and filler interaction is affected by several chemical compounds. The reactivity (calcium compound and water solubility) and the harmful fines (actual clay content and organic content) are the two significant characteristics of these interactions. Filler materials that are used in the pavement industry can be divided into ordinary fillers and the imported filler. As andesite, basalt, caliche, dolomite, granite, volcanic ash, and limestone are categorized as ordinary fillers, whereas fly-ash, furnace slag, and hydrated lime are categorized as imported fillers (6).

Filler materials were initially added to the dense-graded asphaltic concrete mix to fill the voids in the aggregates skeleton and to reduce the voids in the mix (7). Many studies have been conducted on the use of different fillers in various paving mixes. Even though filler particles are tiny in size, it is well documented that filler exerts a significant impact on the properties and qualities of asphalt concrete mixture. A good packing of the coarse and fine aggregates and filler provides a strong backbone for the mix (8). More filler content incurs well-built pavement characterized to superior asphalt cohesively and superior internal stability. However, the excess amount of filler may weaken the mix by increasing the amount of asphalt needed to coat the aggregates (9).

Sawdust is an organic waste material obtained from the mechanical milling of timber into various shapes and sizes (10). Its combustion sources the ash. The properties of asphalt concrete are improved by the addition of a high amount of Calcium oxide (CaO). The modification of the asphaltic concrete mixed with different percentages of sawdust ash significantly and positively affected the properties of the asphaltic concrete (11).

The sawdust carbonized in oxygen-less condition can be used to replace the traditional filler in HMA concrete by the weight of aggregate. The replacement and addition rates of wood sawdust identified by considering the Marshall properties. Replacing and adding carbonized wood sawdust and reusing HMA waste reduces the cost incurred of filler materials when it is compared with using conventional fillers for asphalt concrete production (12).

Physically, sawdust ash is a lightweight material from its specific gravity of 2.29, whereas it contains calcium oxide, silica, alumina, iron oxide, sulfur oxide, potassium oxide, magnesium oxide, tungsten oxide, and phosphorous oxide chemically as the major constituents of oxides.

Calcium oxide, the meaningful content of SDA and significantly enhances the properties of asphalt concrete. The modification of asphalt concrete mixed by varying the amount of sawdust ash significantly and changes the properties of the asphalt concrete (11). Sodium chloride features an enormous role within the improvement of the properties of the bitumen. Sometimes, it is adverse effects on minimizing the strength of the bituminous mixes. The steadiness value of the bituminous mixes decreases gradually with an increase in salt content in bitumen. The penetration value and relative density increases and softening point, flush & fire point, solubility, and ductility of bitumen decrease with increasing salt in pure bitumen, which indicated that the adhesion and cohesion properties of bitumen were reduced with increasing the proportion of salt in bitumen. The tolerable salt limit in the mix varied from zero to five percent (13).

2. MATERIALS AND METHODS

For this study, the basaltic rock of coarse aggregate (CA) and fine aggregate (FA) with desirable strength, hardness, toughness, relative density, and shape were chosen and taken from the Jimma district Ethiopian Road Authority (ERA) quarry site. The physical properties of aggregates are summarized in Table 1. Bitumen 60/70 penetration grade was taken from the Jimma district ERA batch plant. The properties of bitumen are presented in Table 2.

Table 1: Physical Properties of Aggregates

Physical Properties	Test Method	CA	FA	ERA Standard Value
Aggregate Crushing Value, %	BS 812,104	16.70	-	<25
Aggregate Impact Value, %	ASTM C 128	14.21	-	<30
Specific Gravity	AASHTO T 84	2.613	2.636	2.4-2.6
Flakiness Index, %	BS 812, 110	24.70	-	<45
Loss Angeles Abrasion, %	AASHTO T 96	12.60	-	<30
Fines Value, %		90.40	-	N/A

Table 2: Physical Properties of Bitumen

Property test	Test Method	Result	ERA Standard Value
Penetration	AASTO T-49	93	85-100
Ductility	AASTO T-51	100	100+
Specific gravity	AASTO T-228	1.02	1.01-1.03
Softening	AASTO T-53	45	42-51
Flashpoint	AASTO T-48	280	≥232
Solubility	AASTO T-44	99.34	≥99
Loss on heating	AASTO T-47	0.04	≤100

— Fillers

Basaltic stone dust (BSD) and SDA were used as filler material for this research study. Basaltic stone dust was collected from the same quarry site aggregate is taken. The raw SD was collected from Jimma city timber industries. The SDA was obtained from the burnt sawdust at 30°C with fire. The gradation, plastic index, and specific gravity of BSD and SDA were tested in the laboratory. The test results are shown in Table 3.

Table 3: Physical Properties of Filler Materials

Sieve Size (mm)	Test Method	BSD	SDA	ERA Standard Value
0.6	AASHTO M-17	100	100	100
0.3	AASHTO M-17	95.6	98.7	95-100
0.075	AASHTO M-17	83.5	86.4	70-100
Plastic Index	AASHTO M-17	0	2.6	≤4
Specific Gravity	ASTM D-854	2.55	2.549	-

— Chemical composition of SDA

The chemical compositions of SDA obtained by X-ray diffraction are presented in Table 4. The result indicated, SDA contained the following elemental oxides and compounds: Calcium pyrophosphate (Ca2H2O8P2) 38.00%, Calcite (CaCO3) 28.90%, Quartz (SO2) 24.20%, Potassium nitrate (KNO3) 6.40%, Sodium Chloride (NaCl) 1.00%, Carbon graphite 2H (C) 0.60%, Periclase (MgO) 0.60 %, Potassium Chloride (KCl) 0.20% respectively.

Table 4: Chemical composition of SDA

Chemical composition	Content (%)
$Ca_2H_2O_8P_2$	38.0
$CaCO_3$	28.9
SO_2	24.2
KNO_3	6.4
NaCl	1.0
C	0.6
MgO	0.6
KCl	0.2

— Mixture design

Marshall Stability test is carried out to determine the optimum bitumen content. Test specimens are prepared by varying percentages of bitumen from 4.5% to 6% by the weight of aggregates with a 0.5% increment for each variety of fillers. Sample preparation, compaction, and testing were conducted following

ASTM D1559 for all specimens. The mixture prepared from basaltic filler with 100% was named as control. Marshall Stability and flow tests were carried out, where the cylindrical sample specimen was put in the water bath at 60°C for a period of half-hour so compressed on the tangential surface at a constant rate of two-inch/min until the most loads were reached. The governed resistance load and flow value were recorded. The bulk specific gravity and density, theoretical maximum specific gravity and percent air voids were determined for each specimen. In Table 5, the mixture properties with BSD and SDA are shown. A detailed description of replacements and the optimum bitumen content (OBC) of mixtures are presented in Figure 1. As it was observed in Figure 1, the use of SDA in asphalt concrete production filler increases the OBC due to more absorption of the SDA compared with basaltic dust.

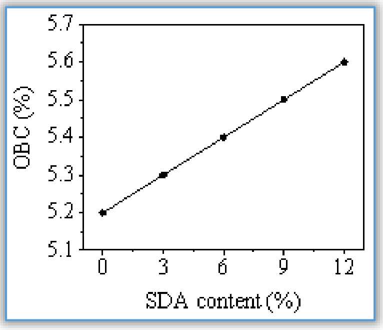

Figure 1: Effect of SDA on OBC

Table 5: Marshall properties with CSD and SDA

Mix Properties	CSD	SDA	ERA Standard Values
OBC, %	5.2	5.6	4-10
Unit weight, g/cc	2.31	2.15	-
Air void, %	4.26	10.12	3-6
Stability, KN	11.27	8.94	≥8
Flow, mm	3.63	3.33	2-4
VMA, %	20.91	25.90	≥14
VFB, %	71.60	55.55	65-73

— Indirect tensile fatigue test

The indirect tensile fatigue test evaluates the fatigue performance of the mix. The fatigue process was assessed in three distinct stages. In the beginning, failure and fatigue fracture started. Next, as cracks were propagated to other areas, and reduces pavement resistance. Finally, as a sudden failure of the pavement was revealed (14). The fatigue life of the samples was quantified by constant stress mode by about frequent loads with fixed amplitude in lined with the diametrical axis of the sample.

The relationship between tensile strain and the number of cycles to failure for each material was developed. A linear relationship was registered when the strain was plotted against the numbered cycles to failure, and the fatigue life prediction equations were developed (15). The fatigue equations were developed using regression analysis, which was in the form of Wohler's fatigue prediction model (Equation-1).

$$N_f = K_1 \left(\frac{1}{\varepsilon_t}\right)^{-K_2}, \qquad (1)$$

where N_f is the number of cycles to failure of the specimen; ε_t is the applied strain; k_1 and k_2 are the coefficients related to mixture properties.

— Indirect tensile strength test

The striping resistance of the mixture was assessed by the decrease in the loss of the indirect tensile strength (ITS) after immersion in water for 24hrs at a temperature of 60°C (16). In this research study, the moisture susceptibility of asphalt concrete was evaluated by performing a tensile strength ratio (TSR) test. For this purpose, cylindrical samples were tested in dry and wet conditions at 25°C. The samples in wet conditions were placed in a vacuum to reach the saturation level of 55-80%. Vacuum saturated samples were kept in an 18°C freezer for 16hrs and then placed in a 60°C water bath for 24hrs. All the samples were brought to a constant temperature, and the indirect tensile strength was measured on both dry (unconditioned) and wet (conditioned) samples. The sample was removed from the bath. Its thickness was determined, and then between the bearing plates of the testing machine, it was placed on its side. Steel loading strips were placed between the specimen and the bearing plates. A load was applied to the specimen. By forcing the bearing plates together at a constant rate of 50.8mm per minute, as per Equation (2):

$$S = \frac{2P}{\pi Dt}, \qquad (2)$$

where S is indirect tensile strength (KN/m_2); P is the peak value of the applied vertical load/repeated load (KN); t is the mean thickness of the test specimen (m), and D is the specimen diameter (m).

The indirect tensile strength ratio was determined using (Equation-3):

$$TSR = 100\left(\frac{S_{cond}}{S_{uncond}}\right), \qquad (3)$$

where S_{cond} is the average indirect tensile strength of the wet specimens and S_{uncond} is the average indirect tensile strength of the dry specimens

— Permanent deformation tests

The experiment was carried out to evaluate the resistance of mixture to permanent deformation are the Marshall test, the static creep test, the dynamic creep test, and the wheel-tracking test (17). For this research, the resistance to permanent deformation of SDA mixtures was investigated using static creep and dynamic creep tests accordingly. The static creep test is used to quantify the creep deformation of the cylindrical specimen under a uniaxial static load as a function of time. The deformation values were quantified with a linear variable differential transducer. The experiment was carried out for all mixtures at the optimal content of asphalt binder. Since the risk of permanent deformation was higher, the uniaxial load of 0.4mpa, the temperature of 40°C, and the load duration of 10^4s were chosen. The dynamic creep test applies a repeated pulsed uniaxial stress on an asphalt specimen and measures the resulting deformations in the same direction using linear variable differential transducers. The dynamic creep test was carried out by applying the dynamic stress of 100kpa at 40°C for an hour. In each test, the specimen sides were capped and placed in the loading machine under conditioning stress of 10kPa for 600s. Next, the conditioning stress was removed, and the stress of 200kPa was applied for 10^4cycles.

3. RESULTS AND DISCUSSION

The samples made from basaltic stone dust (BSD) and sawdust ash fillers showed that the values of unit weight increases to some extent then decreases. The reason behind it is as the content of bitumen increases in the mixture, it fills the voids and increases its unit weight. The sawdust ash specimen revealed a higher percentage of air voids (10.12%) and low unit weight (2.15g/cc) in comparison, basaltic crushed stone dust. Even though the stability, VMA, and flow are satisfactory, the air void and VFB at 100% SDA replacement were not satisfied with the standard. This could be achieved by replacing basaltic crushed stone dust with SDA in 3%, 6%, 9%, 12% and 15% by weight of BSD as shown in Table 7. The result indicated that the SDA couldn't satisfy the ERA standard specification when it is replaced basaltic stone dust beyond 12% in the production of asphaltic concrete.

Table 7: Effect of SDA on Marshall properties mixture

Mixture property	Replacement amount of SDA						ERA Standard value
	0%	3%	6%	9%	12%	15%	
Unit weight	2.31	2.27	2.25	2.22	2.21	2.18	-
Air Void	4.26	4.53	4.72	4.89	5.12	6.26	3-6
Stability	11.27	10.99	10.70	10.51	10.36	10.22	≥8
Flow	3.63	3.49	3.35	3.21	3.07	2.68	2-4
VMA	20.91	21.15	21.39	22.03	22.86	23.28	≥14
VFB	71.60	70.09	69.58	68.07	66.55	63.43	65-73

— Indirect tensile fatigue test

The outputs of the indirect tensile fatigue test are shown graphically in Figures 2 and 3. These graphs were drawn through the average outputs of each specimen at each strain level, and the results revealed the normal relationship between the initial tensile strain and the fatigue life of the mixture. The SDA mixtures had a higher number of cycles to failure than the BSD mixture. It was also found from these figures that the number of load cycles to failure increased as the amount of SDA in the filler increased. Due to more OBC, SDA mixtures can give a more elastic mixture resulting in better fatigue life, consistent with high pulse counts in the indirect tensile fatigue test. The mixture with more flexibility can absorb and disperse stresses produced by fatigue loading, which may result in the delay of damages for asphaltic concrete.

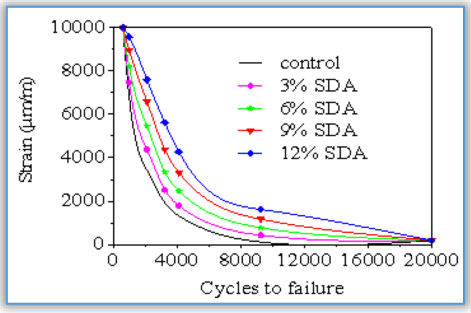

Figure 2: Mixtures fatigue behavior at 15°C.

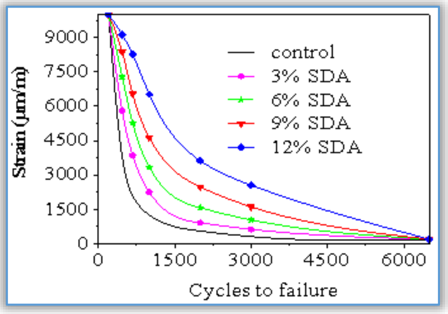

Figure 3: Mixtures fatigue behavior at 20°C.

The fatigue life of 3%, 6%, 9%, and 12% sawdust ash of mixtures at 15°C were 7468, 8200, 8959 and 9562 cycles to failure that are 1.1, 1.2, 1.3 and 1.4 times respectively when compared with the control mixture. Also, with increasing the temperature to 20°C, the fatigue life of all specimens decreased. This behavior was due to the high susceptibility of asphalt to temperature, as identified in previous studies (18)(19)(20). The mixtures with SDA revealed more sensitivity to temperature increase because of more OBC of these mixtures in comparison to the control mixture.

The fatigue equations are shown in Table 8 for every type of the mixture two different variations of temperatures. As shown in Figure 8 (a) and (b), it could be observed that all values of K_1 and K_2 increased when sawdust ash was added, which resulted in an increase in the number of cycles to failure for asphaltic concrete.

— Indirect tensile strength test

The indirect tensile strength of mixes under the dry and wet conditions of samples is given in Figure 4. It was observed that the indirect tensile strength results of wet mixes are lower in comparison with dry mixes. This may happen because the presence of water causes a reduction in asphalt-aggregate adhesion, and thus the strength of asphaltic concrete samples decreases under loading. Also, it can be observed that the loss of indirect tensile strength of the sawdust treated mixtures due to moisture condition was not as high as that of the control mixture. SDA improves asphalt-aggregate adhesion, which does not allow water to displace asphalt from the aggregate surface. Figure 5 shows the tensile strength ratio for samples prepared with different SDA contents. The data also show that the dry and wet tensile strength ratio is significantly improved with the addition of SDA, which led to better resistance against moisture damage. All of the tensile strength ratio values of the SDA treated mixtures were relatively above 80%. The replacement of 3%, 6%, 9%, and 12% SDA to mixtures was increased tensile strength ratio by 1.43%, 2.86%, 4.67%, and 6.64%, respectively, compared with the control mixtures. The specimen with 12%SDA had the highest TSR value, indicating that SDA could be good in preventing moisture damage.

— Permanent deformation tests

The results of static creep are shown in Figure 6. The values of the dynamic creep test are given in Figure 7, showing permanent deformation versus load cycles. The results of the static creep tests show that the samples without SDA had more permanent deformation than the samples containing 3%, 6%, 9% and 12% SDA as filler; these additions resulted in reductions in permanent deformation of 6.89%, 15.33%, 23.74%, and 27.84%, respectively, compared to the control samples. The values of the dynamic creep tests show that the use of SDA as filler also resulted in decreased permanent deformation. The use of 3%, 6%, 9% and 12% SDA as filler resulted in reductions in permanent deformation of 8.58%, 16.14%, 23.17% and 30.75%, respectively.

The experiments revealed that the best replacement for reducing permanent deformation was the replacement of basaltic crushed stone dust with SDA could be 12%.

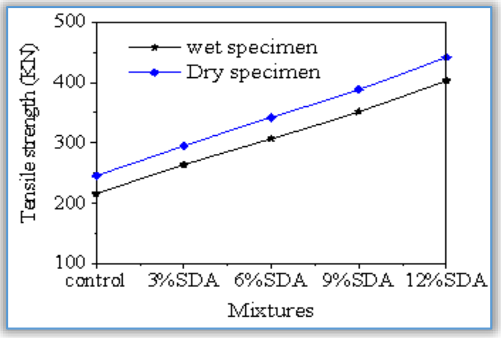

Figure 4: ITS of dry and wet specimens

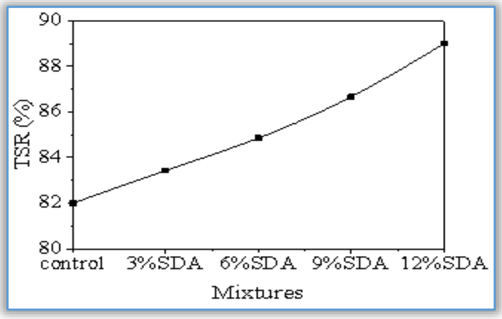

Figure 5: TSR of specimens

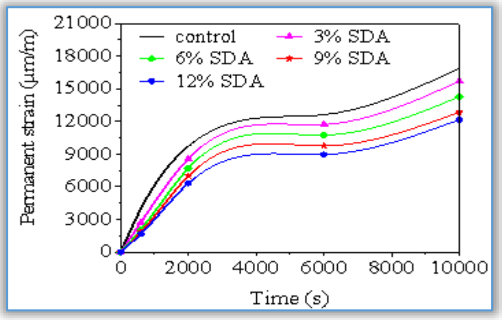

Figure 6: Deformation behavior with time

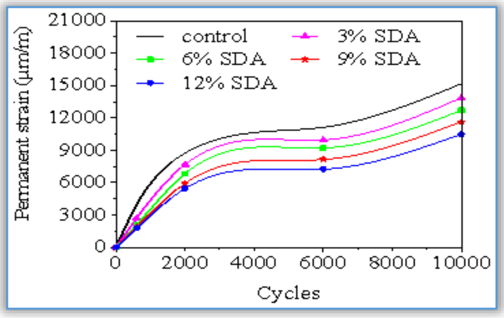

Figure 7: Deformation behavior with cycle

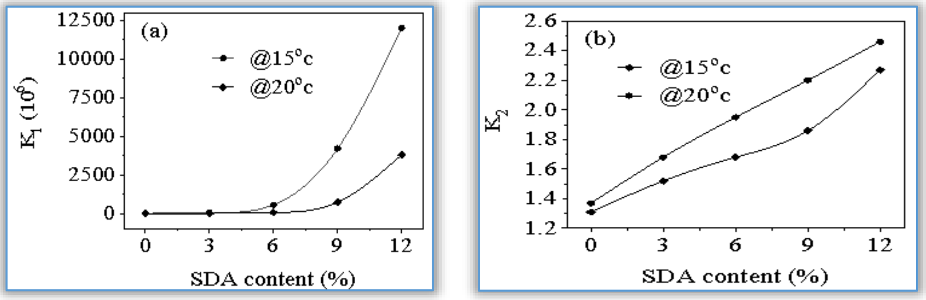

Figure 8: Coefficients of mixture properties

Table 8: Fatigue prediction equations of mixtures

SDA (%)	0	3	6	9	12
N_f @15°C	$3.0x10^6\varepsilon^{-1.31}$	$5.6x10^7\varepsilon^{-1.52}$	$6.6x10^8\varepsilon^{-1.68}$	$5.2x10^9\varepsilon^{-1.86}$	$1.0x10^{10}\varepsilon^{-2.27}$
N_f @20°C	$9.0x10^5\varepsilon^{-1.37}$	$6.9x10^6\varepsilon^{-1.68}$	$6.9x10^7\varepsilon^{-2.95}$	$7.3x10^8\varepsilon^{-2.20}$	$9.8x10^9\varepsilon^{-2.46}$

— Chemical Composition of SDA

The high content of ($Ca_2H_2O_8P_2$) indicates the improvement of the stiffness or the moisture resistance of the asphalt pavement mixture. The presence of quartz (SO_2) in the ash indicates the materials produce a mixture with excellent resistance to permanent deformation and fatigue cracking. The presence of calcium carbonate in the ash increase the fatigue life of asphaltic concrete by reducing the effect of rutting potential and moisture damage potential (20). The presence of calcite in the ash reduces shrinkage effect, increase impact, and improve the surface finish of the pavement. The presence of Carbon graphite 2H(C) in the ash has the advantages to strain-stress self-monitoring, traffic monitoring, border monitoring, and structural vibration control. It also enhances the tensile strength and long-range connecting effect of asphalt.

3. CONCLUSION

The basaltic crushed stone dust can be replaced with the optimum value of 13% SDA as filler material in asphalt concrete production as per ERA standard specification. The result obtained from indirect tensile strength and fatigue tests revealed that SDA could be used as filler up to 12%. Replacing basaltic crushed stone dust with 100% SDA led to higher absorption of bitumen. Replacing with 12% of basaltic crushed stone dust filler by SDA improved the fatigue life of the asphaltic concrete. As the temperature increased, the fatigue life of specimens decreased. This behavior has resulted from the high sensitivity of asphaltic concrete to temperature. Both the static creep and dynamic creep experiments revealed that the addition of SDA as a filler could reduce the permanent deformation of the mixtures. The high concentration of calcium carbonate in the ash reduces the rutting and moisture damage potentials.

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