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Determination of the Optimum Lime Content for Asphalt Concrete Using Marshall Mix Design

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Abstract- This study evaluates asphalt concrete with and without hydrated lime using the Marshall mix design method with the aim of determining the optimum amount of lime required to modify the asphalt concrete. The hydrated lime was added by the dry method to the aggregates blend of asphalt mix with different percentages of hydrated lime (1.0 - 8.0 %) and the bitumen content ranged from 5.5% to 7.5%. The optimum binder and lime contents were found to be 6.5 % and 2.0%, respectively. The Marshall stability of the asphalt concrete with hydrated lime at 2% was 8.69 kN, while that of unmodified asphalt was 6.96kN, indicating that introduction of lime results in better performance. Generally, the lime modified asphalt samples had stability in the range of 4.12kN to 8.69kN, while the unmodified asphalt has stability in the range of 5.49 kN and 6.96kN. Both the lime-modified and unmodified forms conform with the General Specification, Road and Bridges. The flow values for the asphalt samples with lime were between 2.0 and 3.5 mm for 5.5% - 6.5% bitumen content, while the unmodified samples have values between 2.5 and 3.5 mm but both did not meet the specifications at higher bitumen content. The study showed that it is a good idea to introduce lime into asphalt, as it will result in production of asphalt mixture.

Keywords- Hydrated lime; Asphalt; Marshall; Stability; Flow

I. INTRODUCTION

Road transportation is the oldest and cheapest method when compared with other modes of transportation like water and air transportation. It provides flexibility of route choices as well as door to door services. Therefore, it complements the other modes of transportation. Because of the increased need for road transportation and the increase in axle load, researchers have sought to improve the performance of road pavement. The focus of the present study is on flexible pavement (Asphalt Concrete). Different materials have been introduced into the asphalt mix to improve its properties. These include rubber, sulphur, phosphoric acid, fly ash, blast furnace slag, and lime, among others. This research has the objectives of determining the optimum amount of lime required to modify the asphalt mix. Introduction of lime into the asphalt has become inevitable due to increased traffic load in Nigeria where the rail system that could serve as an alternative means of conveying freight is grossly underdeveloped or nearly comatose. Hydrated lime has been found to provide many benefits in asphalt mixtures. According to Little and Epps [1] hydrated lime has the ability to control water sensitivity and, act as an antistripping to inhibit moisture damage, active filler, anti-oxidant and additive that reacts with clay fines in HMA, thus stiffening the asphalt binder and HMA, improving resistance to fracture growth, altering oxidation kinetics and interacting with products of oxidation to reduce their deleterious effects and altering the plastic properties of clay fines to improve moisture stability and durability.

Hydrated lime has been seen to be more than a moisture damage additive, as it reduces chemical ageing of the bitumen and stiffens the mastic more than normal mineral filler above room temperature [2]. All these properties impact durability, and hydrated lime is now seen has an additive to increase asphalt mixture durability [2]. Kim et al. [3] evaluated the performance changes and fundamental material characteristics associated with moisture damage due to various anti-stripping additives in asphalt mixtures using various experimental approaches and a numerical simulation. They considered three additives: a reference additive, hydrated lime, and two alternative additives: fly ash and cement, which were added into two types of mixes (SP2 for low-traffic-volume roadways and SP5 for high-traffic-volume roadways) where two different asphalt binders (PG 64-22 for the SP2 mix and PG 70-28 for the SP5) were used [3]. They employed two asphalt concrete mixture scale performance tests, the AASHTO T-283 and the APA under water, and two local-scale mixture constituent tests, the boiling water test (ASTM D3625) and the pull-off test to characterize the effects of binder-specific anti-stripping additives on the binder-aggregate bonding potential in mixtures [3]. The pull-off tensile strength tests were then numerically modelled through the finite element technique incorporated with the cohesive zone modelling approach to seek more fundamental scientific insights into the effect of each anti-stripping additive on the overall moisture damage resistance [3]. Results from their laboratory tests and numerical simulations indicate that the SP5 mixtures, where high-quality aggregates and polymer-modified binders were used, were fairly self-resistant to moisture damage without treatment with any anti-stripping additive and did not show any visible sensitivity among additives, whereas the effects of additives and their sensitivity were significant in the SP2 mixes that used the unmodified binder PG 64-22 and low-quality aggregates [3]. The hydrated lime was reported to perform slightly better than other additives, particularly with its longer moisture-conditioning time [3].

The Georgia Department of Transportation carried out field studies involving more than 125 paving projects. Samples of lime-treated HMA (cores) were obtained from the projects and a visual evaluation of stripping was made. The average tensile

strengths of the cores showed that lime was effective as an antistripping agent [4]. Peterson et al., [5] in studies at the Western Research Institute (WRI) found that the introduction of lime into asphalt reduced its age hardening. Johansson [6] studied the reaction of hydrated lime with bitumen and observed that the use of 20 percent hydrated lime by mass produced a significant increase in creep stiffness but did not increase physical hardening. His study also showed that at low temperatures lime-modified bitumen had greater potential to dissipate energy through deformation than the unmodified bitumen, thus providing better resistance to thermal loading [6]. Hopman [7] reported on a research program at the Technical University Delft where stripping and Marshall stability tests were carried out on different types of bitumens and aggregates with varying lime contents. He stated that all the specimens containing hydrated lime showed less stripping and improved stability, and that the best results were achieved in mixtures in which hydrated lime replaced 10 to 15% of the mineral filler, which was typically 7% by weight of the mixture [7].

Also, Sebaaly [8] summarized research and development studies carried out in the past 20 years that compared hydrated lime and liquid antistripping additives on moisture damage of hot mix asphalt mixtures. He grouped the studies into two: the first group consists of three studies that used the Hamburg wheel tracking device, and the second group comprises seven studies that measured the engineering properties of the HMA mixtures [8]. He concluded that the three studies with Hamburg wheel tracking devices showed that while lime-modified asphalt mixtures might experience minor rutting, they had excellent resistance to moisture damage [8]. The second group considered tensile strength, resilient modulus, shear strength and fatigue resistance, and they proved that lime was effective in reducing moisture damage of HMA mixtures and the HMA was less affected by freeze-thaw cycles, more stable and less susceptible to rutting than other liquid additives [8]. All these indicated that the addition of lime could be used to a positive effect in Nigeria.

Roads in many developing countries are characterised by many failed spots/sections. Failures such as rutting and cracks have been observed. These are generally caused by the increase in truck traffic volumes and weights, changes in the properties of materials used in producing the asphalts mixtures when subjected to loading and environmental conditions and the workmanship. Therefore, it is high time that, we started modifying the asphalt mixtures to improve the performance of asphalt pavements. Hydrated lime has been highlighted by different researchers to improve resistance to water damage and mechanical properties of the asphalt. The challenge therefore is to determine the optimum amount of lime required in the asphalt mixture, and that is what this study aims to achieve using the Marshall mix design method, which is used for asphalt mixture design.

II. MATERIALS AND METHOD

The materials used are aggregates, bitumen and hydrated lime. The materials and the method are described in detail below.

A. Materials

The materials used for the experiment are: 19mm aggregates, 10mm aggregates, quarry fines (stone dust), bitumen and hydrated lime. The mineral filler used for this experiment was quarry fines (stone dust) only. It consists of grain particles with at least 75% passing through 0.075mm sieve. The hydrated lime was in powdered form. It was observed to be a very smooth and whitish in colour. Straight run bitumen with penetration grade 60/70 was used for the study.

B. Methods

The aggregates, after being oven-dried, were subjected to a mechanical sieve analysis (one after the other) to determine the grading in accordance with BS 1377 [9] for the mix proportioning, so as to obtain a blend of aggregates that conforms with the Federal Ministry of Works Specifications [10]. Several mix proportions were tried until an acceptable mix was obtained - 30% of the 10mm, 10% of the 19mm and 60% of the stone dust. Then, an asphalt mixture was prepared without lime with the bitumen content ranging from 5.5% to 7.5%. Also the lime-modified asphalt mixture was prepared with same bitumen content range and lime contents ranging from 1% to 8%. A Marshall test was performed on the samples (cores) from unmodified and lime-modified asphalt mixtures to determine the stability, flow and the bulk density.

The samples were prepared by weighing 2400g of the blend of aggregates into a pan and heating in an electric oven to about 150°C. The samples were removed from the oven and varying percentages of Lime (ranging from 1% to 8%) were added to the mix in order to produce the Lime-modified asphalt concrete samples. Hot bitumen heated to about 150°C was added to each mix in varying percentages ranging from 5.5% to 7.5% of the total mix. The mixture was stirred continuously and uniformly until all aggregates were thoroughly coated. The control specimens (without addition of hydrated lime) were prepared using the same approach and conditions.

Then 1200g of the hot asphalt mixture (out of 2400g produced) was transferred into a cylindrical shape mould (100mm by 75mm) for manual compaction, giving it 75 blows of the Marshall compacting rammer on its face. The base plate and the collar were removed, filter paper replaced and the reversed face of the specimen was positioned and given another 75blows of the rammer.

On completion, the collar was removed and the mould containing the specimen was carefully transferred unto a smooth flat surface where the specimen (compacted asphalt) was extracted from the mould and allowed to stay overnight at room temperature. The Marshall stability, flow and density of the samples were determined. The specimen was brought to test

temperature by immersing in water bath for 20 to 40 minutes. The guide rods and the inside surfaces of the test heads were thoroughly cleaned. The guide rod was lubricated so that the upper test head slides freely over them. The specimen from the water bath was placed in the lower segment of the breaking head. The upper segment of the breaking head was placed on the specimen, and the complete assembly was placed in position on the testing machine. The flowmeter was placed in position over of the guide rods and the sleeve was held firmly against the upper segment of the breaking head while the load was applied. The flow meter was adjusted to zero prior to the start of the test. The load was applied to the specimen at a rate of 50 mm per minute until the maximum load was reached and load began to decrease. The maximum load was recorded, and the flowmeter was removed from its position over the guide rod the instant the load began to decrease. The flow value was read and recorded. The elapsed time for the test from removal of the sample from the water bath to the maximum load determination did not exceed 30 seconds.

III. RESULT AND DISCUSSION

The Marshall stability, flow and density results of the lime-modified and unmodified asphalt are presented and discussed in this section. The test was carried out in accordance with the American Standard for Testing and Materials, ASTM D6927 – 15 [11].

A. Marshall Stability

Fig. 1 shows the Marshall Stability results for the Lime-modified specimens and unmodified specimens at equal bitumen contents (5.5% to 7.5%). The unmodified asphalt mix specimens had marshal stability values ranging between 5.49 kN and 6.96 kN, while the hydrated lime modified asphalt samples had marshal stability values from 4.12 kN (6.0% hydrated lime content) to 8.69 kN (2.0% hydrated lime content). Specimens with lime contents between 1.0 – 3.0% and 3.5 – 5.5% showed significant improvement in stability over the unmodified samples; when the lime content was increased to 6% and above, the Marshall stability values reduced from 5.59 kN to 4.12kN, which is even lower than the unmodified samples. The reason for the increase in stability can be attributed to the stiffening effect of the hydrated lime (being an active filler) and improved bonding between aggregates and bitumen which resulted from the precipitation of calcium ions from hydrated lime onto the aggregates' surface. Although the stability reduced, when more lime was added, the values recorded met the Government of Nigeria Specifications for roads and bridges, which state that Marshall stability values must be greater than 3.5kN. The reduction in stability as the lime content is increased could be attributed to the increased surface area of the fine content requiring more bitumen to form active mastic.

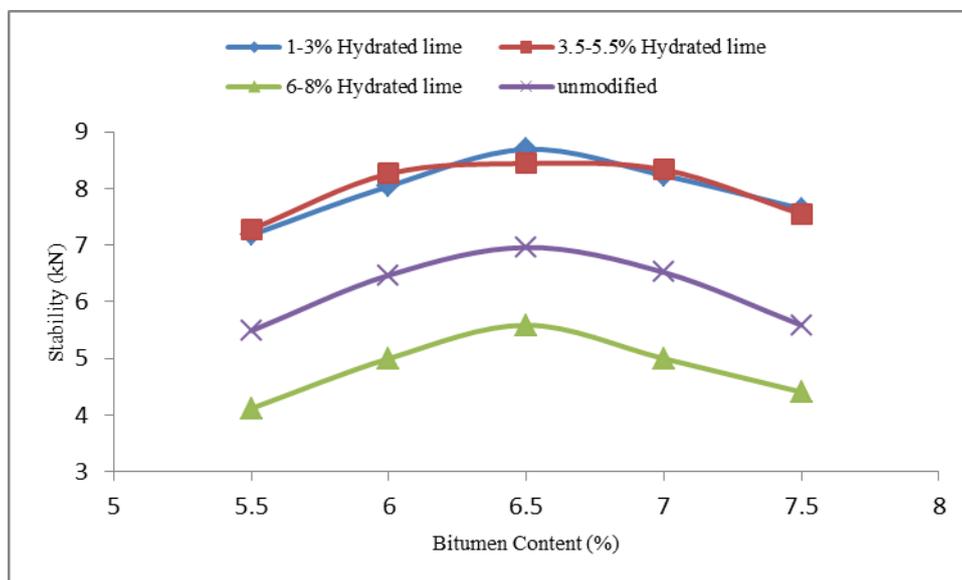


Fig. 1 Marshall stability results for both Lime-modified and unmodified asphalt specimens

It was observed that the optimum marshal stability values were recorded at 6.5% bitumen content for all samples tested. At 6.5% bitumen content and for 1% to 3% lime content, the best stability was of 8.69 kN was obtained with hydrated lime of 2.0%, for 3.5% to 5.5% lime content, the best stability of 8.44 kN was recorded when the hydrated lime content was 4.5%, while for the 6% to 8% lime content, lime content of 7.0% gave the best result of 5.59 kN stability. The unmodified sample has stability value of 6.96 kN stability at 6.5% bitumen. The study shows that the optimum amount of lime required to modify the asphalt is 2%.

Fig. 2 shows the relationship between Marshall stability (kN) and lime content (%). It is observed that at 5.5%, 6% and 7% bitumen contents, as the lime content was increased, there was an initial increase in the Marshall stability values, which reduced as the lime content was further increased. At 6.5% and 7.5% bitumen contents, there was gradual decrease in the

Marshall stability as the lime content was increased. Generally, increasing the lime content above the optimum resulted in reduction in the stability. This established the fact that the optimum value that will give the best result must be determined. The results showed that the highest stability of 8.69 kN was obtained with 6.5 % bitumen content and 2 % lime content.

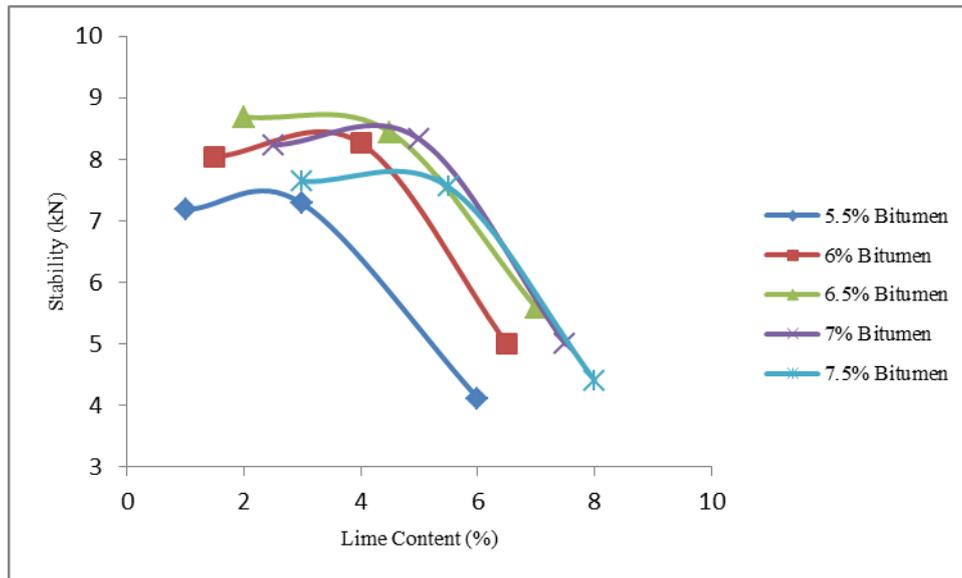


Fig. 2 Marshall stability versus lime content with varying bitumen content

B. Marshall Flow

Fig. 3 shows the relationship between the asphalt flow and the bitumen contents for the lime-modified and unmodified asphalt concrete specimens. It was observed that the flow values increase with the bitumen contents. Generally, the results show that the addition of lime to the asphalt reduces its flow. However, as shown in the stability results, increasing the lime content beyond the optimum results in a reduction in stability. The flow values for the lime-modified asphalt with 6-8% hydrated lime were found to be the lowest of the ranges evaluated, while the values for 1-3%, 3.5-5.5% and unmodified asphalt did not have significant difference. At 6.5% and 2% bitumen and lime contents, respectively, which resulted in the best stability, the flow was found to be 3.5 mm. This value met the specification of the Government of the Federal Republic of Nigeria Road and Bridges specification that the flow value must be within 2-4 mm [10].

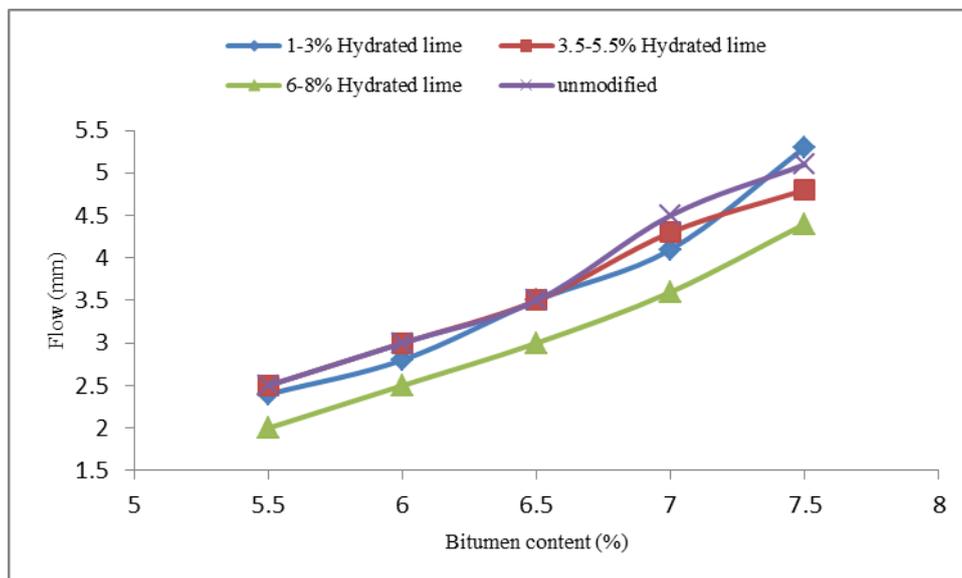


Fig. 3 Flow (mm) versus bitumen content for varying lime content

Fig. 4 shows that at 5.5% to 7% bitumen content, there was an initial increase in the flow values of the specimens when the lime content was increased, but it decreased with a further increase in lime, while at 7.5% bitumen content, there was steady decrease in the flow value as the lime content increased. At optimum bitumen content (6.5%) for the asphalt concrete performance, there was no initial increase in the flow (3.5mm) for the asphalt when it was initially increased, but it later decreased when the lime content was further increased from 4.5% to 7.0%. The reduction in flow could also be associated with

the stiffening effect of the hydrated lime.

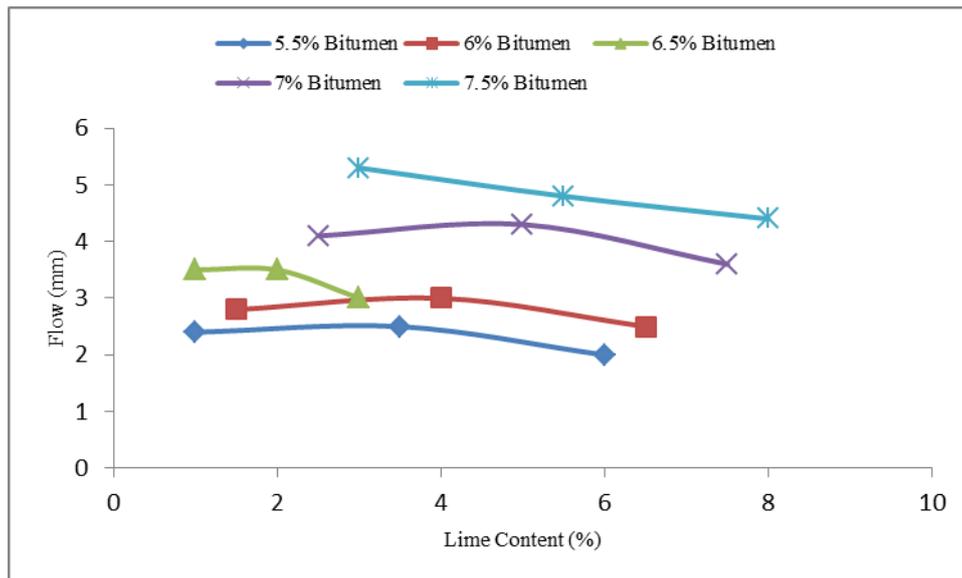


Fig. 4 Flow versus lime content for varying bitumen content

C. Marshall Density

The bulk density results are shown in Fig. 5. The results show that when hydrated lime was added to the asphalt, especially from 1.0% to 5.5%, the density was greater than that of the non-modified asphalt, while the density was less with the addition of 6-8% lime. This increase in density could be associated with the aggregation of fine particles, making the asphalt better compacted than when asphalt lime was not introduced and when there was excess lime.

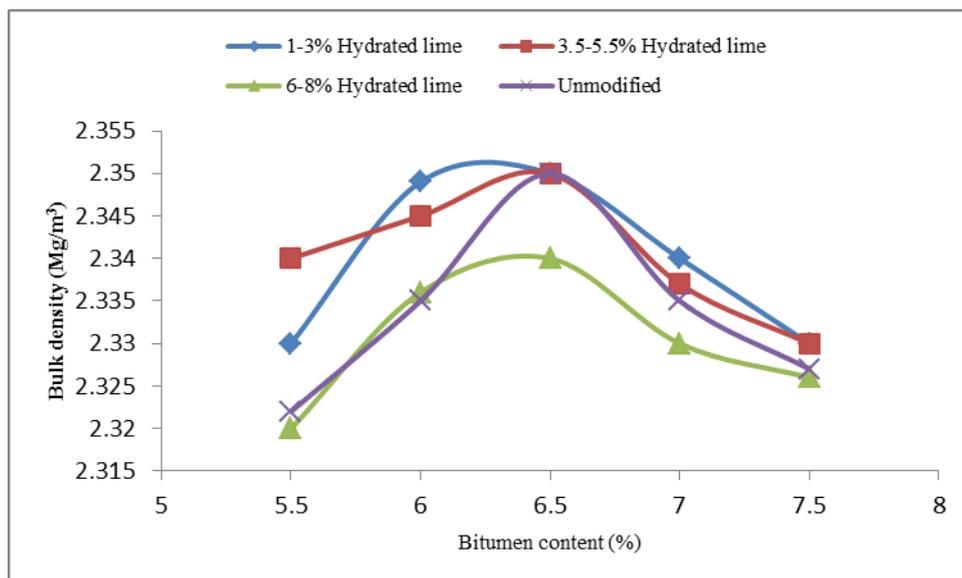


Fig. 5 Densities of lime modified and unmodified asphalt

IV. CONCLUSIONS

The results of the study showed that the use of hydrated lime to modify asphalt causes an increase in the stability of the asphalt, if used in the right proportion. The stability was found to improve when the lime content ranges from 1 to 3% and 3.5 to 5.5%, while the stability reduced with the addition of 6 to 8% lime. Also, the results showed that the flow increased with increasing lime content, with the asphalt samples with 6 to 8% having the lowest flow. This could be associated with the increased fine content of the asphalt. It was found in the study that the optimum binder and lime contents required to modify the asphalt are 6.5% and 2%, respectively.

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