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# Complementing the Quantity of Quarry Dust Filler with Lime in Hot Mix Asphalt

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**Abstract**
This study was undertaken to evaluate the effect of quarry dust fillers and hydrated lime on stability and volumetric properties of asphalt. The optimum binder content was determined from asphalt produced with 100% quarry dust regarded as the control mix. The predetermined optimum binder content of the control was used for production of all mixes which includes: 75%granite dust and 25% lime, 50% granite dust and 50% lime, 25% granite dust and 75% lime and 100%granite dust and 0% lime. The aggregates, bitumen and asphalt mix were subjected to various testing. The tests include: sieve analysis test, specific gravity test, aggregate impact and crushing value test, softening point test, water absorption test, flash and fire point test and marshal stability test. Results obtained showed that the optimum binder content was obtained at 6%, the specific gravity of sand, granite dust and granite was 2.67, 2.62 and 2.58 respectively. Marshal Stability result showed that the stability decreased with increase in lime content from 14.5 kN for the control to 5.3 kN for the mixture containing 100% of filler as hydrated lime. The flow and volumetric properties mostly complied with the specification given by Federal Ministry of Works and Housing, FMWH (1997) apart from the voids filled with bitumen (VTB) for which some values were less than the specified. The study underscores that the use of quarry dust fillers remain a better option as it requires lesser amount of bitumen for better strength and volumetric properties.

**Keywords**: asphalt, flexible pavement, lime, mix design, stability, volumetric properties

## 1. Introduction

Asphalt is a composite mixture of aggregate (sand, crushed rock or gravel, slags), binder (bitumen) and filler materials (quarry dust or stone dust) in their correct proportion used for construction and maintenance of flexible pavement, railway tracks, airport runways, hydraulic structures (bridges, culverts), bicycle lanes, sidewalks and also play and sport areas Murana et al. (2013). Regardless of the thickness or type of asphalt pavement, the load is transmitted through the aggregate with the bitumen serving as a cementing agent to bind the aggregate in proper position so as to transmit the applied wheel loads to underlying layers where the load is finally dissipated (Nwakaire et al., 2020; Mallick and El-Korchi, 2009). Asphaltic pavement design is unsatisfactory without the incorporation of filler materials. Mineral filler consists of very fine, inactive mineral matter extracted during aggregate crushing that is suspended in the asphalt binder to improve the density and strength, fill voids and also stiffen and toughen the mixture. Fillers are generally selected on the basis of their ability to increase the stiffness of the binder mastic, dispersion of binder (bitumen), adhesion of bitumen to aggregate and accelerates curing of compacted mixture (Huang et al., 2010).

Fillers are beneficial in the production of asphalt mixtures, as they can substantially affect the physical and mechanical properties of the mixtures especially the effect of aggregate binding (Grabowski and Wilanowicz, 2008).

Recently, there have been a global demand for extensive study on the strength of asphalt produced with the incorporation of this filler material as the asphalt strength have been greatly undermined which could invariably affect the service life and quality of the asphalt used for flexible pavement construction. The role of fillers on the strength of asphalt has been greatly undermined in asphalt production, this development have been attributable either to poor quality control in the mix design of the asphalt components or the inherent strength of the filler material used for asphalt production. Some construction companies fail to ensure the adequacy of filler amounts in asphalt mixtures due to insufficiency of mineral fillers from crushed granite (Nwakaire et al., 2021). The use of other fine materials like lime as alternative to mineral fillers is the obvious solution to the insufficency of mineral fillers.

Studies on the use of hydrated lime in hot mix asphalt (HMA) have revealed multiple benefits as it was found to act as active filler, anti-oxidant, and as an additive that reacts with clay fines in HMA (Dallas and Jon, 2001). Among many additives tested by Dallas and Jon (2001), hydrated lime was found to be best in reduction of moisture sensitivity of asphalt and as such was recommended as a satisfactory anti-strip additive. Studies have found that incorporation of lime into asphalt mixtures can result in reduction of hardening age, increase in flexural stiffness, and improvement of asphalt resilient modulus (Albayati and Ahmed 2013; Albayati, 2012). Satyakumar et al. (2013) studied three types of mineral fillers including hydrated lime. They discovered that adding 1.5% of hydrated lime by the total weight of specimens raises the stiffness modulus up to 55%. Huang, et al. (2010) studied the effect of lime particle fineness on asphalt mixtures, the results revealed an increase of tensile strength ratio and other mechanical properties were found to be satisfactory. However, some studies reported that high content of hydrated lime can result in high bitumen content at optimum mix design. For instance, Albayati (2012) reported that a high binder content of 5.34% was gotten as optimum binder content when 3% hydrated lime was added whereas the optimum binder content was as low as 4.73% when there was 0% hydrated lime content.

In order to proffer solution to the problem mentioned, this study did investigate the strength properties of asphalt produced with partial and complete replacement of quarry dust filler with lime. The strength of asphalt produced with 0% replacement of quarry dust filler with lime as control, 25%, 50%, and 70% replacement of quarry dust filler with lime as partial replacement and 100% replacement of quarry dust filler with lime by weight of quarry dust filler was evaluated. This helped to buttress the need to utilize lime as filler in situations where insufficiency of quarry dust filler would hinder adherence to standard specifications.

## 2.0 Materials and methods

### 2.1 Material Sourcing and Preparation

#### 2.1.1 Fillers

The hydrated lime used for the experimental study is designated as LM, it was procured from the marked and was safely stored in laboratory during the testing period. The lime was used to replace the quarry dust filler (designated as QD) content of the HMA sample in increasing percentages of 25%, 50%, 75%, and 100%. The percentage replacement was computed by dry weight of quarry dust filler.

#### 2.1.2 Bitumen

The bitumen used is 60/70 penetration bitumen designated as BT in this paper. The laboratory tests conducted on the bitumen include; Flash point (in accordance with ASTM D92), Penetration (in accordance with ASTM D5), and Softening point (in accordance with ASTM D36) tests to ascertain their adequacy for practical applications.

#### 2.1.3 Aggregate (Fine and Coarse)

The granite and sand samples used are designated as GT and SD. The following laboratory tests were conducted to determine the index properties of the aggregates; Sieve analysis test, Specific gravity and water absorption test (in accordance with ASTM C127 -07 and ASTM C128 – 07), Bulk Density test (in accordance with ASTM C127 -07 and ASTM C128 – 07), and aggregate impact value test (in accordance with BS812: Part 3) .

### 2.2 Marshal Stability Test of Asphalt

The Marshall Stability test method is widely used for the design and control of asphalt concrete and hot rolled asphalt materials (Nwakaire et al., 2020b). The asphalt stability value (kN) is a measure of strength of asphalt mix and indicates the maximum load that the compacted specimen can carry at standard test temperature of $60^0$C while the flow value (mm) is a measure of flexibility of asphalt mix and indicate the change in diameter of the sample in the direction of applied load between the start of loading and the time of maximum load (Olumide, 2016). The

Marshal mix design carried out in this study was in accordance with the procedure given by ASTM D1559 for samples preparation, stability and flow determination, as well as ASTM D2726 for volumetric properties evaluation.

## 3.0 Result and Discussion

### 3.1 Properties of Aggregate

Here are the key findings obtained from experimental investigation of the asphalt components and the asphalt mix. These findings are valuable in understanding the effect of replacement of quarry dust fillers with hydrated lime on strength properties of asphalt. The physical properties of the aggregates used are presented in Table 1.

**Table 1: Physical Properties of Aggregates used for the Research**

| Properties | SD | QD | GT | FMWH, (1997) |
|---|---|---|---|---|
| Specific Gravity (Gs) | 2.67 | 2.62 | 2.58 | 2.5 – 2.9 |
| Water Absorption (%) | - | - | 0.98 | 0.2% - 1.5% |
| Impact Value | - | - | 6.4 | |
| Crushing Value | - | - | 7.2 | |
| Loosed Density ($kg/m^3$) | 1466.67 | 1566.67 | - | ≥ 1700$kg/m^3$ |
| Compacted Density ($kg/m^3$) | 1483.33 | 1750.00 | - | ≥ 2000$kg/m^3$ |
| Coefficient of Uniformity (Cu) | 4.75 | 21 | 14 | - |
| Coefficient of Curvature (Cc) | 1.1 | 14.7 | 12.8 | - |
| Gradation | SP | SP | GP | - |
| AASHTO Classification System | A-2-4 | A-2-4 | A-1-b | - |
| USCS Classification System | SM | SC | GC | - |

Table 1 depicts the index properties of the aggregate samples used for the study. Assessment of the index properties of sand and granite dust used for the asphalt production shows that the specific gravity of sand, granite dust and granite were 2.67and 2.62 and 2.58. According to AASHTO classification system, sand and granite dust were classified as A-2-4 whereas granite was classified as A-1-b. According to the Unified Soil Classification System, the sand and granite dust were classified as SM (sand mixed with silt) and SC (sand mixed with clay) respectively. The bulk density of granite dust in loosed and compacted state was higher than that of sand. Assessment of the gradation properties of the granite dust and sand revealed that both samples were poorly graded.

Strength evaluation of the coarse aggregate used for the asphalt production showed that the impact and crushing values of granite were 6.4% and 7.2% respectively. These values satisfied the requirement given by Federal Ministry of Works and Housing, (1997) which states that the impact and crushing values of aggregate used for asphalt production must not exceed 30%. This implies that the aggregates has satisfactory impact strength. The conformity in index and strength properties of aggregate to relevant standard justified the use of the selected aggregate for the study. Figure 1 shows the gradation curves for the coarse and fine aggregates.

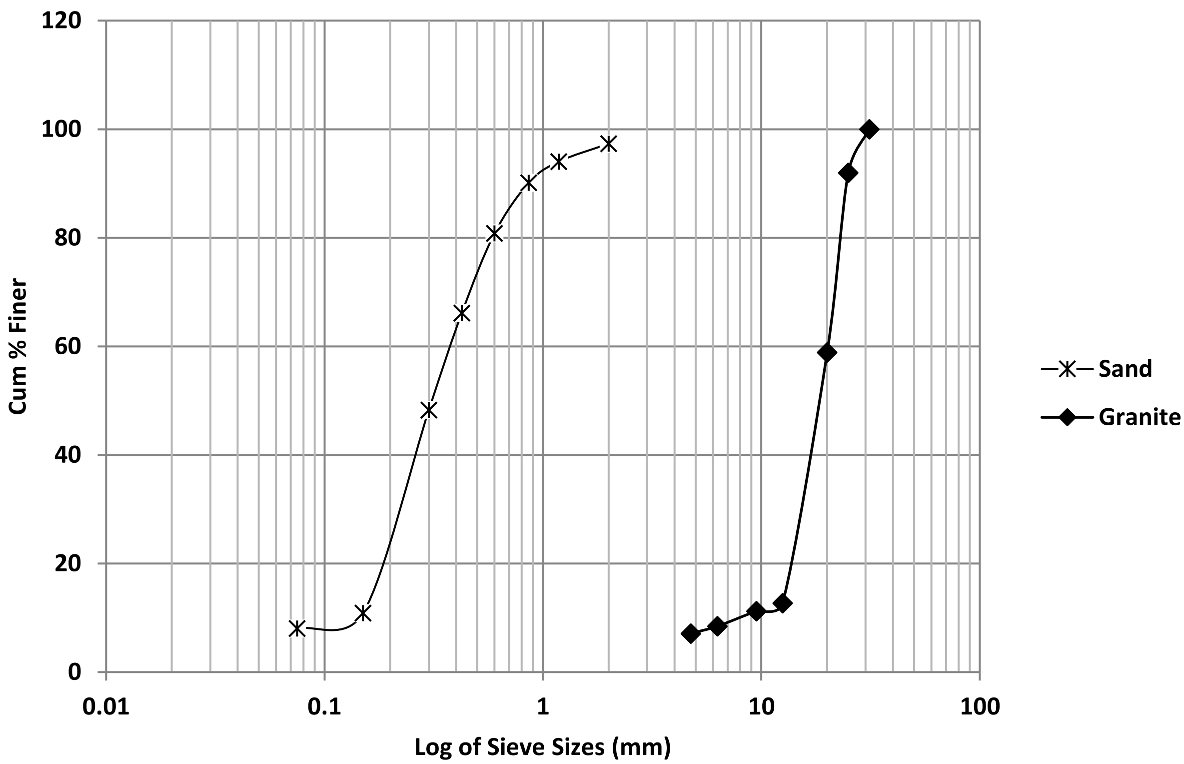


**Figure 1: Particle Size Distribution Curve for the aggregates**

**3.2 Properties of Bitumen**

Table 2 depicts the properties of bitumen used for the study. These results were compared with the specification of FMWH (1997) to ensure compliance with the standard.

**Table 2: Properties of Bitumen used for the Research.**

| **Properties** | **Values** | **FMWH, (1997)** |
|---|---|---|
| Penetration (0.1mm) | 60 | 60 – 70 |
| Softening Point | $48^0$C | $48^0$C – $56^0$C |
| Specific Gravity | 1.02 | >1.0 |
| Fire point | $288^0$C | $280^0$C – $300^0$C |
| Flash Point | $304.8^0$C | >$250^0$C |

The flash and fire point test was conducted to determine the temperature at which bitumen will give a flash and burns for a minimum of five (5) minute. The result obtained as shown in Table 2.0 revealed that the flash point obtained for the bitumen was $304.8^0$C; this value is within the acceptable range ($300^0$C – $320^0$C) by FMWH (1997). In the same vein, the average fire point obtained for bitumen was $288^0$C. This value lies within the specified range ($280^0$C – $300^0$C) and it shows that the bitumen can be used for the production of asphalt.

The specific gravity of bitumen was 1.02 which conforms to the standard set by FMWH (1997) which states that the specific gravity of bitumen used for asphalt production must exceed 1.0. The softening point of the bitumen was also found to be adequate. These results justifies the use of bitumen for the study.

**3.3 Determination of Optimum Binder Content**

The mix design conducted on the conventional mix was done using the Marshall mix design methodology. The summary of the average values of the stability and volumetric properties of the asphalt specimens at different binder contents are shown in Table 3. Figures 2 to 5 are plots of the relevant mix design parameters for determination of the optimum binder content.

**Table 3: Summary of Stability and Volumetric Properties of Asphalt at Different Binder contents**

| % Bitumen/Properties | 5 | 5.5 | 6 | 6.5 | 7 |
|---|---|---|---|---|---|
| Bulk Density (gm/cm$^3$) | 2.403 | 2.418 | 2.424 | 2.412 | 2.406 |
| Stability (KN) | 10.4 | 12.2 | 14.5 | 10.4 | 9.2 |
| Flow (mm) | 2.1 | 2.8 | 3.4 | 4.1 | 4.7 |
| Air Void (%) | 5.7 | 4.4 | 3.4 | 3.1 | 2.6 |
| VMA (%) | 17.3 | 17.3 | 17.5 | 18.3 | 19.0 |
| Specific Gravity | 2.548 | 2.528 | 2.509 | 2.490 | 2.471 |
| VFB (%) | 67.6 | 74.6 | 80.6 | 86.3 | 86.3 |

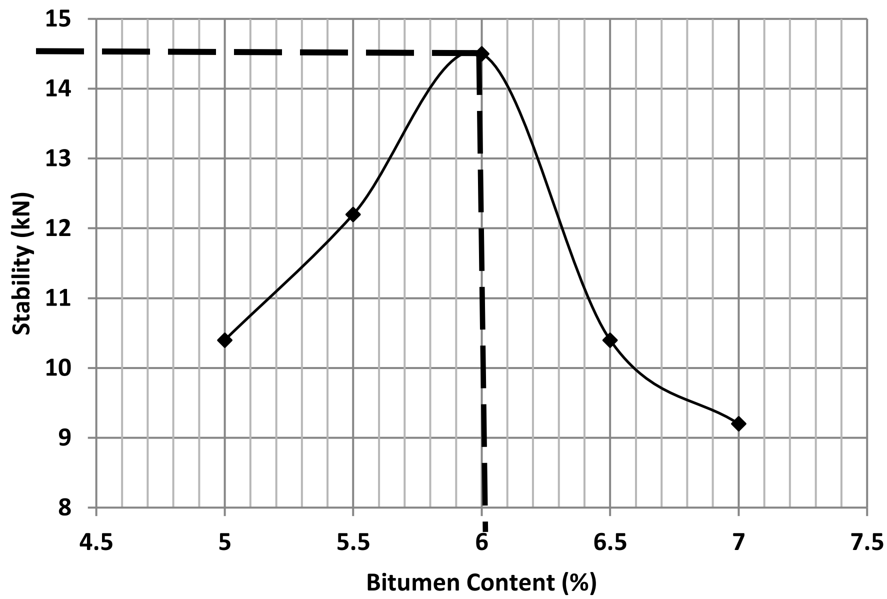


**Figure 2: Graph of Stability Vs Bitumen Content**

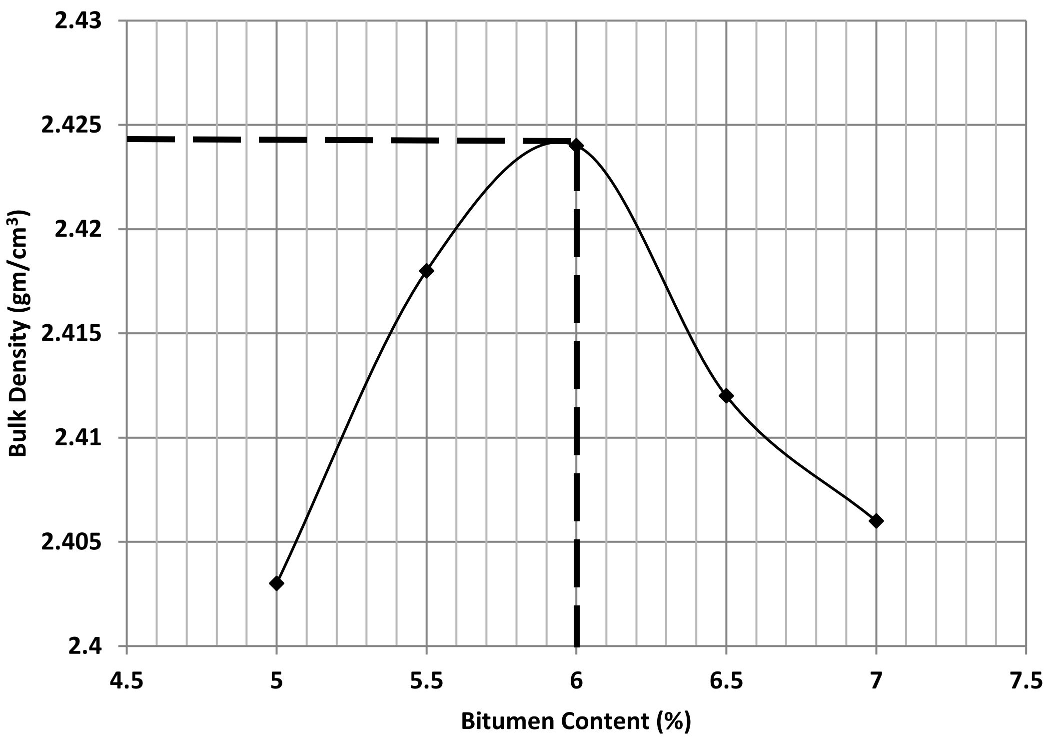


**Figure 3: Graph of Bulk Density Vs Bitumen Content**

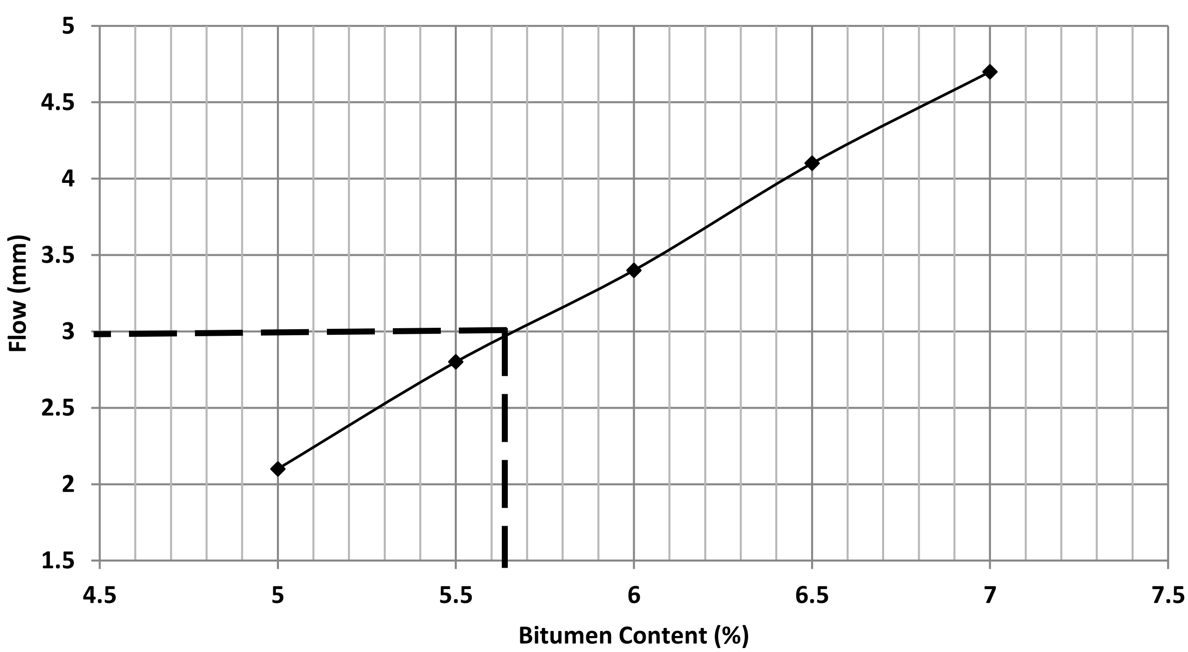


**Figure 4: Graph of Flow Vs Bitumen Content**

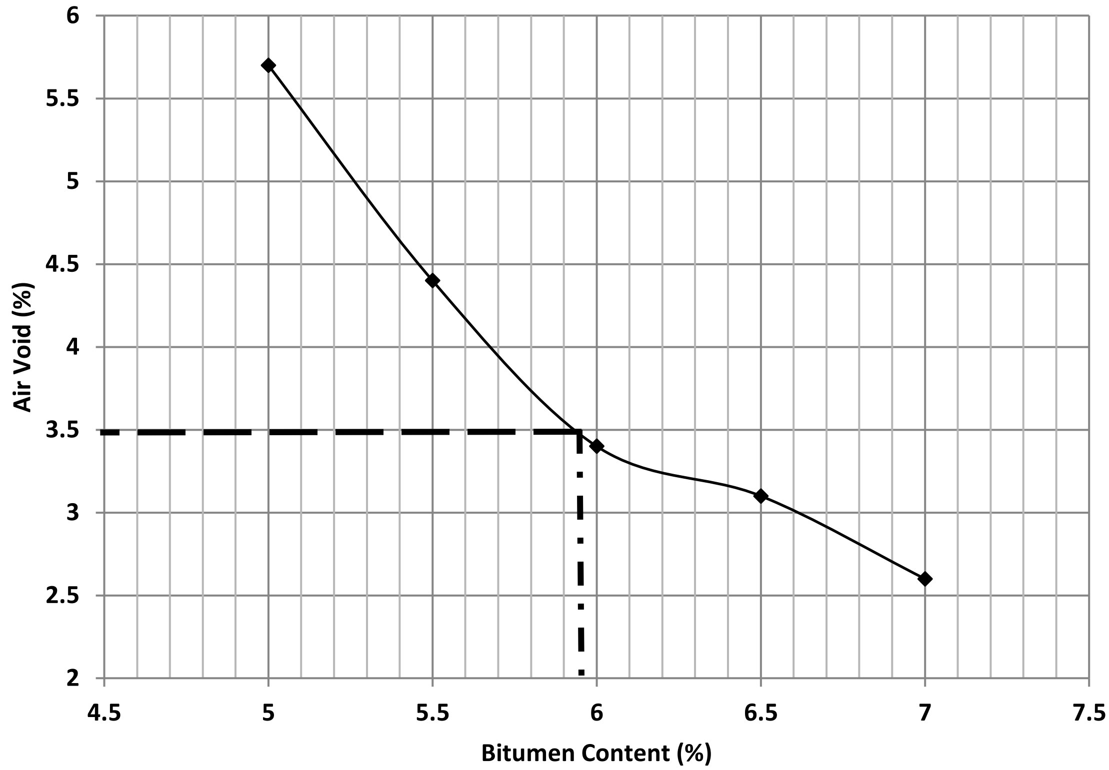


**Figure 5: Graph of Air Void Vs Bitumen Content**

The optimum binder content corresponds to the amount of bitumen required to yield maximum stability or other volumetric properties of the asphalt mix. The optimum binder content determined for the control mix is the average of the optimum binder from the stability, bulk density, air voids, and flow curves, this is 6% as shown in the figures. This result implies that at 6% bitumen content, the best performance of the asphalt mixture would be expected. This binder content was used for all the other mixtures containing different amounts of lime fillers in order to ascertain the changes in stability and volumetric properties of the mixtures.

**3.4 Stability and Volumetric Properties of Asphalt Containing different amounts of Hydrated Lime**

The effect of replacement of quarry dust filler with hydrated lime was studied by producing asphalts containing different amounts of quarry dust and hydrated lime filler. The Flow and volumetric properties of the asphalts at 6% binder content are shown in Table 4.

**Table 4: Flow and Volumetric Properties**

| Properties | Flow (mm) | Void in Mineral Aggregate (%) | Void in Total Mix (%) | Void Filled by Bitumen (%) |
|---|---|---|---|---|
| FMWH, (1997) | 2 - 4 | 10% - 30% | 3% - 5% | 75% - 82% |
| 100%QD | 3.4 | 17.5 | 3.4 | 80.6 |
| 75%QD: 25%LM | 4.3 | 24.4 | 3.6 | 77.0 |
| 50%QD: 50%LM | 3.6 | 26.4 | 3.7 | 76.3 |
| 25%QD:75%LM | 2.5 | 25.8 | 4.2 | 71.2 |
| 0%QD: 100%LM | 2.3 | 27.8 | 4.8 | 65.3 |

**3.4.1 Void in Total Mix**

Table 4 depicts the void in the total mix for asphalt produced with different proportion of mineral fillers. It was observed that the void in the total mix increased on consistent addition of lime to quarry dust. The highest void in total mix was recorded for asphalt mix produced with 100% lime. This result implies that quarry dust is more effective in filling void in asphalt mix than hydrated lime. However, the void in the total mix obtained for the asphalt mix at different mix proportion of quarry dust and hydrated lime satisfies the specifications given by FMWH (1997).

**3.4.2 Void in Mineral Aggregate**

The void in the mineral aggregate for asphalt produced with different mix proportion of quarry dust and lime are shown in Table 4 The highest void in mineral aggregate was recorded for asphalt mix produced with 100% lime while the lowest void in mineral aggregate was recorded for asphalt with 75%QD + 25%lime. Apart from asphalt mix produced with 50%QD + 50%lime, an increasing trend was observed. In all circumstance, the asphalt produced with the different mineral fillers obeyed the specification given by FMWH (1997).

**3.4.3 Void Filled by Bitumen**

The results of void filled by bitumen are shown in Table 4. A decreasing trend was observed from the result of the voids filled by bitumen. Apart from the 25%QD + 75%LM and 0%QD + 100%LM mixtures other mixtures satisfied the FMWH specifications. The reason for violation of the standard could be as a result of using a uniform binder content for all the mixtures. At the respective mix designs of the mixtures, a better performance can be achieved but with a higher amount of bitumen.

**3.4.3 Flow**

The flow values for asphalt produced with varying proportion of mineral fillers are shown in Table 4. The peak flow was recorded for asphalt mix produced with a mixture of quarry dust and lime at 75% QD + 25%LM while the lowest flow was recorded for asphalt produced with 100% lime as fillers. The flow values were found to be satisfactory as reported.

**3.4.4 Stability**

Figure 6 shows the values of stability for asphalt produced at varying mix proportion of quarry dust and hydrated lime. The stability is an indicator to the compressive strength of the asphalt mixtures. Asphalt with high stability is desirable for durable flexible pavement construction. The effect of inclusion of lime on the stability of the asphalt mixtures are shown in Figure 6.

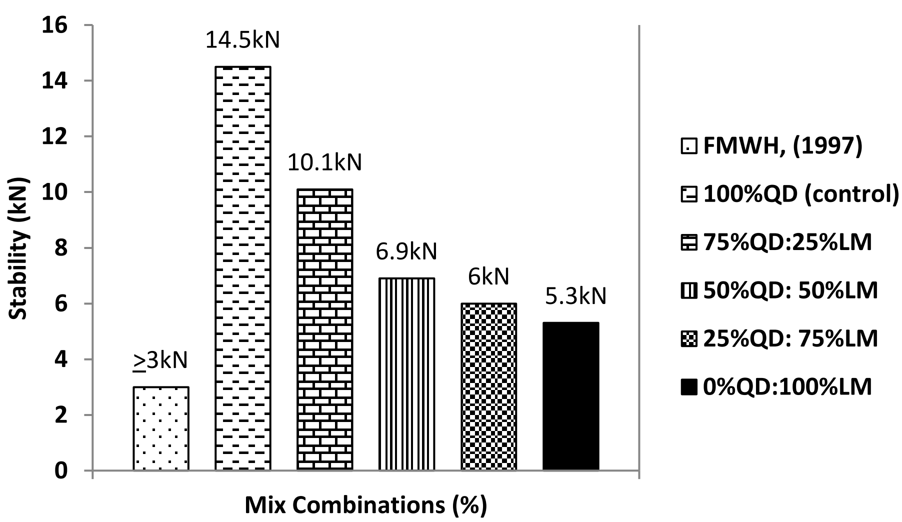


**Figure 6: The Stability of Asphalt Produced with Different Combinations of QD and LM Fillers**

It was observed that addition of lime to quarry dust from 25% to 100% by weight of quarry dust depressed the stability of the asphalt mix. The lowest value of stability was recorded for asphalt produced with 100% lime as fillers. The consistent decrease in the stability of asphalt on addition of lime could be attributed to the stiffening effect of lime. The results obtained suggest that lime has negative effect on the stability of asphalt mix. However, the stability of asphalt mix produced at different mix proportion of quarry dust satisfied the specification given by FMWH (1997).

**4.0 Conclusion**

In this study, the following conclusion in the light of the findings obtained on the effect of quarry dust and lime on strength properties of asphalt can be drawn:

1. The properties of the bitumen and aggregate samples used for the study satisfied the Federal Ministry of Works and Housing requirements for use in asphalt production.
2. The optimum binder content determined using 100% granite dust as control was 6% which was within the acceptable range by FMWH (1997).
3. The flow and Volumetric properties were found to be generally satisfactory, though the control mixture had superior properties.
4. The stability of the asphalt mix produced with varying proportion of mineral fillers decreased with increase of lime content. However, all the values satisfied the specification by FMWH (1997).
5. The study adjudged that granite dust was more effective in ensuring the strength of asphalt than lime.

**5.0 Recommendation**

The following recommendation based on the findings obtained on effect of quarry dust and lime on strength properties of asphalt can be made:

1. The use of quarry dust filler in asphalt mixtures is strongly encouraged however in situations of insufficiency, a combination of lime and quarry dust filler can be encouraged.
2. Proper mix design should be conducted on the mixture for any combination of aggregates chosen. This will ensure optimal performance especially in terms of volumetric properties.

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