Analysis of Physical and Mineralogical Properties of Aggregate on Strength and Durability of Asphalt Concrete

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Abstract

Asphalt is made by mixing aggregates, filler and binder materials together according to pre-determined ratios. Out of the total asphalt weight, 94% to 95% consists of aggregate. It is not surprising that the performance of asphalt concrete mixtures is influenced by the properties of their aggregate blends, such as gradation, shape (angularity and elongation), texture (roughness) and mineralogy. In asphalt concrete, numerous studies have related gradation, shape, and texture of the aggregate to durability, workability, shear resistance, tensile strength, stiffness, fatigue response, rutting susceptibility, and optimum binder content of the mixtures. However, a few has described about the influence of mineralogy on characteristics of asphalt. This research has been carried on to make an effort to fill that gap between the aggregate mineralogical properties and the characteristics of asphalt concrete. Under the research, a number of representative aggregate samples were collected from different quarry sites which are currently used in the process of manufacturing asphalt all over the country. The samples were subjected to a series of tests in order to determine both physical and mineralogical properties. Marshall stability and flow values of the asphalt mixtures were determined to assess the properties of asphalt made using the collected aggregates. Finally, using test results, an analysis was conducted followed by the conclusions made using the test results, a set of recommendations were proposed.

Keywords: Aggregate mineralogical properties, Aggregate physical properties, Asphalt concrete

1. Introduction

After the internal civil conflicts lasted nearly 30 years, huge development programs were commenced all over the country with a safe environment for the investors. Simultaneously, most of the abandoned areas due to the conflicts were resettled. To facilitate all the development and resettlement programs, there is a huge requirement of providing proper access to those areas. To fulfil the requirement, a number of roads and highway projects have been started with most of them still in progress. As a result, there is a growing demand for construction materials.

Information indicates that new highways of length 12,379km, and expressway length of 169 km, and many more to come in the future. And most importantly, almost all these are asphalt paved roads. Other than that, Sri Lanka has one of the densest road networks in Asia [1].

Due to the above reasons, it is very important to find out best ways of enhancing the quality and durability of asphalt concrete roads. To achieve the maximum strength and durability of roads, quality control of construction material and the manufacturing process is very much important and it is a major current concern in the industry.

Primarily, asphalt concrete is a mix of bitumen and a blend of density graded aggregates. Mix proportions of the asphalt concrete are determined after a process of mix design to achieve the desired strength and durability against expected traffic and adverse climatic conditions by using available aggregates [2].

Aggregates must be tough and abrasion resistant to prevent crushing, degradation, and disintegration effects when stockpiled, fed through an asphalt plant, placed with a paver, compacted with rollers and subjected to traffic loadings. These properties are especially critical for open- or gap-graded asphalt concrete mixtures (such as open-graded friction courses and stone matrix asphalt) which do not benefit from the cushioning effect of the fine aggregate and where coarse particles are subjected to high contact stresses. Aggregates lacking adequate physical properties may cause construction and performance problems. Aggregate mineral and physical composition, exposure history of weathering cause stripping, creeping like asphalt problems. Variations in temperature, freeze-thaw cycles, and wetting-drying cycles increase the stripping potential and the nature of water to which the mix is exposed (salt content, pH) affects stripping.

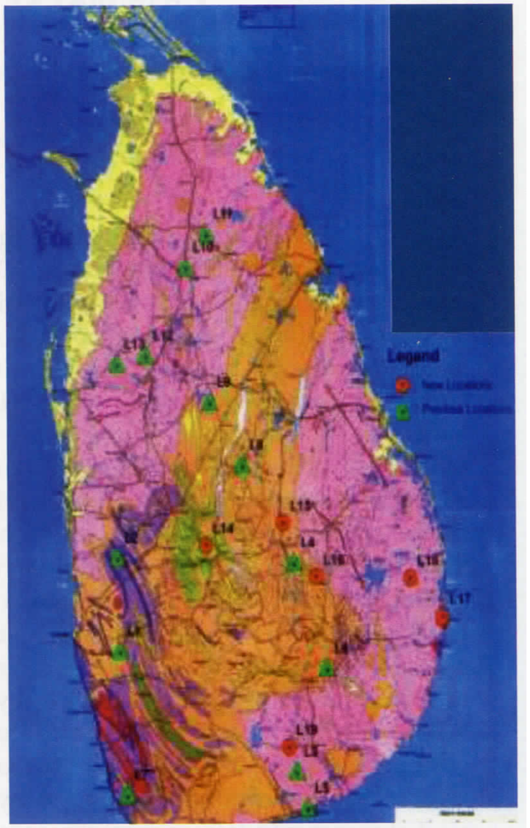

Figure 1 - Sampling locations

Asphalt pavement failure is a complicated phenomenon. It is a result of cumulative damage in different pavement layers. The properties of aggregates used in asphalt concretes are very important to the performance of the pavements for which the asphalt concretes are used. Often, pavement distress such as stripping and rutting can be traced directly to the aggregates used. Proper aggregate selection is necessary for attaining desired performance. Many tests have been developed empirically to assess the relationship between aggregate properties and asphalt quality without indicating a strong relationship with the final product.

The objective of this research is to evaluate the physical and mineralogical properties of aggregates for the asphalt concrete quality and develop an index for ideal aggregate selection for different purposes. Under the research plan, a number of representative aggregate samples were collected which are currently used in the process of manufacturing asphalt in all over the country.

The samples were subjected to a series of tests in order to determine both physical and mineralogical properties of aggregates followed by several more tests to assess the properties of asphalt made using collected aggregates. The data gathered from relavent literature, a similar research conducted in the previous year in the same department, and the results of the above tests conducted under this study were used for the analysis.

2. Methodology

The research methodology consisted of preliminary data analysis, field data gathering and analysis, sample collection, testing, result analysis and the interpretation of the relationship between the quality of aggregates and the durability of the asphalt concrete with recommendations for the selection of suitable source rocks.

2.1 Preliminary Data Analysis

Preliminary data gathering and analysis were conducted prior to the field visits, sample collection and testing, studies were conducted on available research related to asphalt production, asphalt paving, design considerations, properties of aggregates affect in bonding between asphalt and aggregates, asphalt aggregates interactions in the asphalt pavement, testing of asphalt for its durability assessment and testing of aggregates to assess its properties. The knowledge gap in the local industry to identify most suitable source rocks for asphalt cement manufacture was evaluated.

2.2 Field Visit and Sample Collection

This stage of the study was initiated with the collection of quarry data from Geological Survey & Mines Bureau, Sri Lanka (GSMB) in Central, Uva and Eastern Province of the country. The field visit was organized to collect samples from the Highland Complex and the Vijayan Complex of Sri Lanka. During the field visit, aggregate samples of three sizes (chip, ½ "and ¾") were collected from each location. The details of all samples in each location are given in Table 1.

Table 1 - Description of sampling locations

Location		GPS Coordinates	
		Longitude	Latitude
1	Boulder Mix (Pvt.) Ltd., Meepe	6.859°	80.486°
2	Senok Mining (Pvt.) Ltd.,	7.283°	80.088°
3	Kotadeniyawa Sothern Group., Hambanthota	6.316°	81.054°
4	CECB asphalt plant, Mahiyan gana	7.257°	81.045°
5	CML, Hambanthota metal quarry	6.151°	81.111°
6	Darme metal crusher, Yudaganawa	6.779°	81.222°
7	K.D.A. Weerasinghe, Kahatapitiya	6.212°	80.136°
8	Crusher plant, Moragahakanda project	7.700°	80.7698 °
9	Maga Neguma metal quarry, Kekirawa	8.154°	80.0675 °
10	Punawa metal quarry	8.607°	80.446°
11	Access, Vauniyawa metal quarry	8.766°	80.552°
12	Oththappuwa metal quarry	8.253°	80.267°
13	Dammika metal crusher, Saliyawewa	8.09°	80.039°
14	Aladeniya	7.329°	80.58°
15	Alawathugoda	7.433°	80.989°
16	Bandara metal crusher Bathalayaya	7.189°	81.166°
17	Priyadarshani metal crusher,Bibila	7.105°	81.491°
18	Pothuvil	7.008°	81.851°
19	MCL metal crusher ,Damana	7.184°	81.676°
20	Mackstone metal crusher,Thanamalwila	6.422°	81.015°

2.3 Testing

Physical, chemical and thin section analyses were conducted in order to quantitatively analyse the composition and the quality of the aggregate samples collected. Later, asphalt tests were carried out in order to assess the quality of asphalt concrete produced using collected aggregates.

2.3.1 Physical Tests

Bulk Specific Gravity, Uniaxial Compressive Strength (ASTM D7012 - 14), AIV (IS: 2386 - PART IV-1963) and LAAV (ASTM C131), Water Absorption (ASTM C127– 15) tests were carried out in order to evaluate the physical properties of aggregates.

2.3.2 Mineralogical Properties

Silica content by digestion with HF acid (ASTM C1567 - 13), with samples subjected to thin section analysis (ASTM C856-95), the mineralogical content was microscopically observed.

2.3.3 Asphalt Tests

Following characteristics are determined to assess the performance of designed bituminous mixes,

- Binder content and gradation of aggregates
- Flexibility and strength of the bituminous mixture
- Density

Marshall test is a very common test method in Sri Lanka to assess these properties. It was carried out in order to determine the bulk density, stability and flow values of Marshall asphalt specimens.

3. Results and Discussion

3.1 Results

3.1.1 Results of Physical Tests

The results obtained from each physical test (bulk specific gravity test, Uniaxial Compressive Strength test, Aggregate Impact Value test, Los Angeles Abrasion Value test, and Aggregate Soundness test) are tabulated below. Samples from location numbers 14-20 were collected and tested this time.

Table 2 - Summary of physical test results

Location number	AIV %	LAAV %	UCS (MPa)
1	16.16	38.76	NA
2	13.87	34.57	NA
3	16.33	38.72	82.96
4	24.01	47.90	38.21
5	13.62	26.50	102.61
6	26.85	60.45	27.29
7	22.69	32.01	76.41
8	28.03	60.87	30.57
9	15.33	38.48	42.59
10	15.37	38.08	31.66
11	10.38	42.15	31.66
12	16.64	44.67	44.76
13	42.22	32.71	27.29
14	21.074	58.222	33.84
15	27.179	45.34	24.02
16	20.957	48.645	46.94
17	17.458	31.54	73.61
18	16.598	32.52	49.12
19	22.802	38.26	65.65
20	14.236	25.47	35.81

3.1.2 Results of Chemical Analysis

3.1.2.1 Results of the Silica Test

Table 3 - Summary of silica test results

Location number	SiO_2 % (Chemical test)
1	30.49
2	20.92
3	22.38
4	5.56
5	22.2
6	16.78
7	29.68
8	15.99
9	70.53
10	71.45
11	63.18
12	62.02
13	74.4
14	57.55
15	56.49
16	59.54
17	67.71
18	67.61
19	68.45
20	67.06

3.1.2.2 Results of Thin Section Analysis

Thin section analysis was performed to identify the mineral content.

Table 4 - Summary of thin section analysis

Location number	Quartz (%)	Feldspar(%)	Biotite (%)	Garnet (%)	Hornblende (%)	Mica (%)	Zircon (%)
14	56	20	15	0	9	0	0
15	52	21	12	0	9	6	0
16	58	9	11	3	0	10	9
17	57	14	24	0	0	5	0
18	59	19	22	0	0	0	0
19	61	14	19	0	0	6	0
20	60	18	20	0	2	0	0

3.1.2.3 Results of the Asphalt Test

Table 5 - Summary of the asphalt test results

Location number	Stability (kN)	Flow value (mm)
1	24.8	11.2
2	20.66	9.6
3	19.72	12.4
4	22.59	11.6
5	20.67	8.4
6	21.73	11
7	24.52	8.8
8	26.17	10
9	27.22	10.7
10	21.41	10.5
11	24.14	11.1
12	25.22	11.3
13	30.56	8.9
14	19.21	11.2
15	16.25	9.52
16	18.62	8.88
17	16.34	11.12
18	16.25	11.12
19	14.63	9.4
20	16.45	11.76

3.2 Discussion

3.2.1 Analysis of Thin Sections

The thin section analysis was to identify the mineralogy in each rock sample and the influence of each mineral to the physical properties of the rock, and the characteristics of asphalt was determined. From the thin section analysis, following information can be highlighted.

As in Figure 2, the relationship with the UCS value and the quartz percentage of aggregates can be expressed as y= 3.2266x -138.78. Pearson correlation coefficient (r) of UCS vs Quartz content is 0.544 and the P value is 0.207. Quartz percentage has a moderate relationship with UCS value. The relationship with AIV and the quartz percentage of aggregates can be expressed as y= -0.9136x+ 72.641. Pearson correlation of AIV vs Quartz is -0.631 and the P value is 0.129. It is a moderate negative relationship. LAAV and quartz percentage relationship can be expressed as y= 3.2266x-138.76. Pearson correlation of LAAV vs Quartz is -0.498 and the P value is 0.255, again a moderate relationship Generally, LAAV should be below 40 to allow the use on the surface course in road constructions.

Figure 3 shows that the relationship with UCS value and Feldspar percentage can be expressed as y= -2.4944x +87.977. The R value of UCS vs Feldspar curve is -0.601 and The P value is 0.153. Feldspar percentage has a strong negative relationship with UCS value. The relationship with AIV and feldspar percentage of aggregates can be expressed as y= 0.1012x+18.38. Pearson correlation coefficient of AIV vs Quartz curve is 0.100 and the P value is 0.831. It is a very weak positive relationship. LAAV and quartz percentage of aggregates relationship can be expressed as y= 3.2266x-138.76. The R value of LAAV vs Quartz is 0.027 and the P value is 0.954. Again this is a very weak relationship. The calcareous nature of the aggregates weakens the bonds acting as a filler material in aggregates. The metamorphic nature of granites reduces with increasing feldspar content. Therefore, compressive strength of rocks reduces with feldspar content.

According to Figure 4, the relationship with UCS value and biotite percentage can be expressed as y= 0.549x+37.43. Pearson correlation coefficient of UCS vs Biotite is 0.644 and the P value is 0.119. Biotite percentage has a strong relationship with UCS value. The relationship with AIV and biotite percentage of aggregates can be expressed as y=-0.1274x+22.263. Pearson correlation coefficient of AIV vs Biotite curve is -0.696 and the P value is 0.082. It is a strong negative relationship. The relationship with LAAV and Biotite percentage of aggregates can be expressed as y= 1.3582x+63.673. Pearson correlation coefficient of LAAV vs Biotite curve is -0.759 and the P value is 0.048. It is a strong relationship. Increasing Biotite content has a strong relationship of aggregate quality.

As in the Figure 5, UCS value and Muscovite percentage can be expressed as y= 0.6823x+43.976. Pearson correlation coefficient of UCS vs Muscovite is 0.254 and the P value is 0.582. Muscovite percentage seems to have a weak relationship with UCS value. The relationship with AIV and Muscovite percentage of aggregates can be expressed as y= 0.3804x+18.359. The R value of AIV vs Muscovite is 0.543 and the P value is 0.208. It seems moderate positive relationship. The relationship with LAAV and Muscovite percentage of aggregates can be expressed as y= 0.6443x+37.148. Pearson correlation coefficient of curve is 0.245 and the P value is 0. 597. It seems to be a weak relationship. Muscovite seems to have a significant effect on AIV of aggregates.

According to Figure 4 and 6, the test results were unable to show a significant influence from tracer elements such as Garnet and Hornblende, since the number of samples was very small.

3.2.2 Analysis of Silica Test Results

When referring to Figure 8, the relationship with UCS value and SiO_2 percentage obtained by chemical testing can be expressed as y=-0.2385x+59.964. Pearson correlation coefficient of UCS vs SiO_2 percentage is -0.247 and the P value is 0.065. Quartz percentage has a weak relationship with UCS value. The relationship with AIV and the quartz percentage of aggregates can be expressed as y= -0.01x+ 20.564 Pearson correlation of AIV vs Quartz is -0.03 and The P value is 0.107. It is a very weak negative relationship.

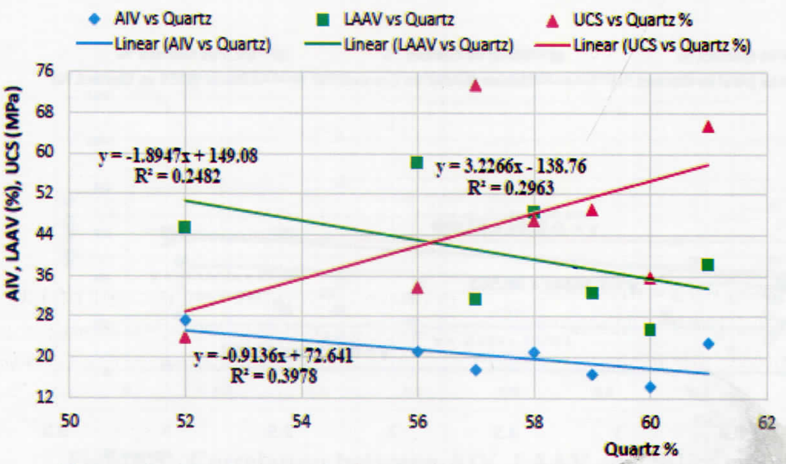

Figure 2 - Variation of physical test results and quartz percentage

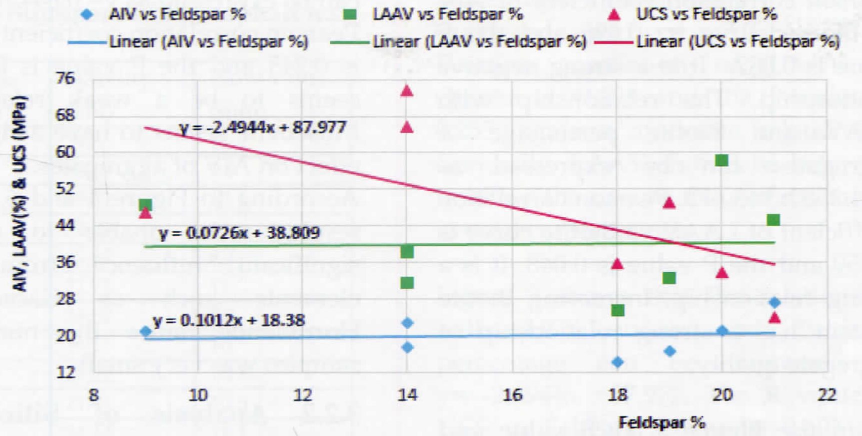

Figure 3 - Correlation between physical test results and Feldspar content

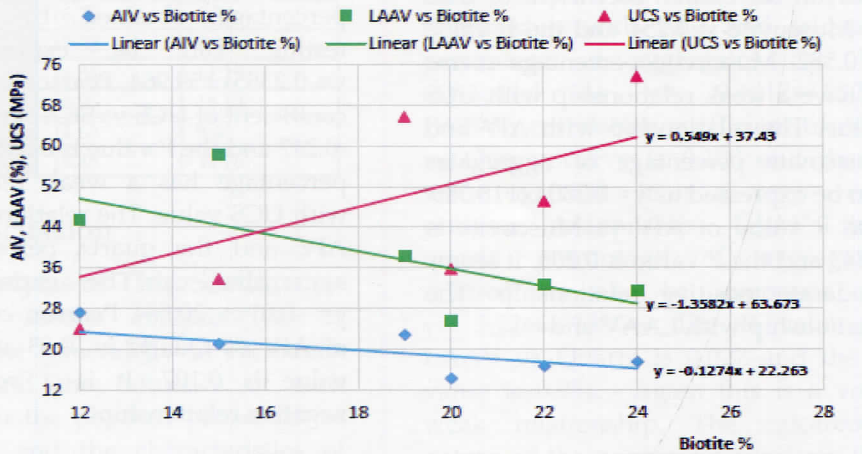

Figure 4 - Correlation between physical test results and Biotite percentag

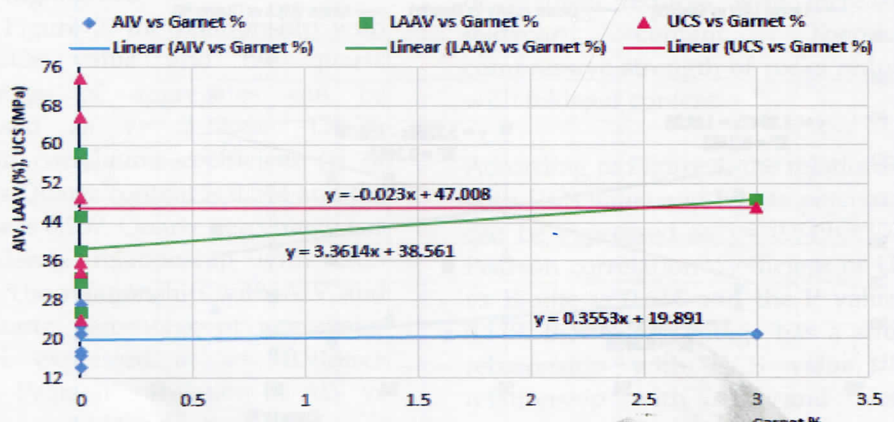

Figure 5 - Correlation between physical test results and Garnet percentage

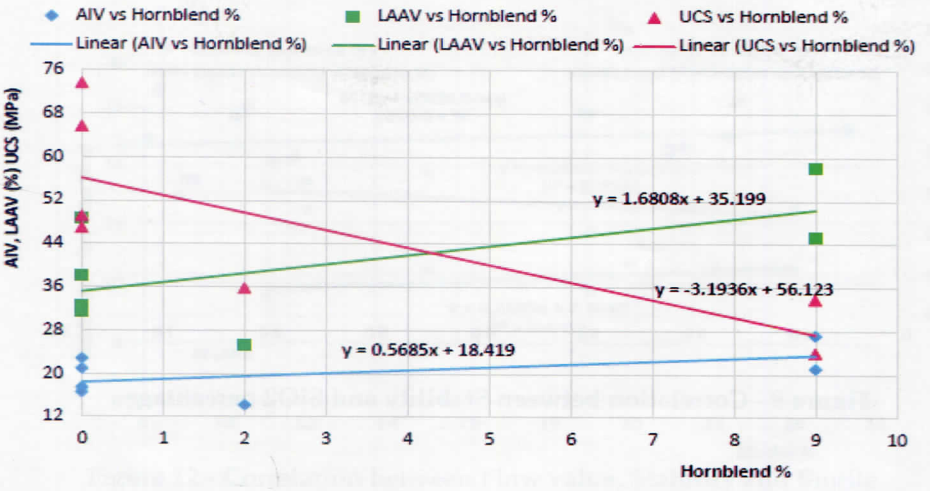

Figure 6 - Correlation between physical test results and Hornblende

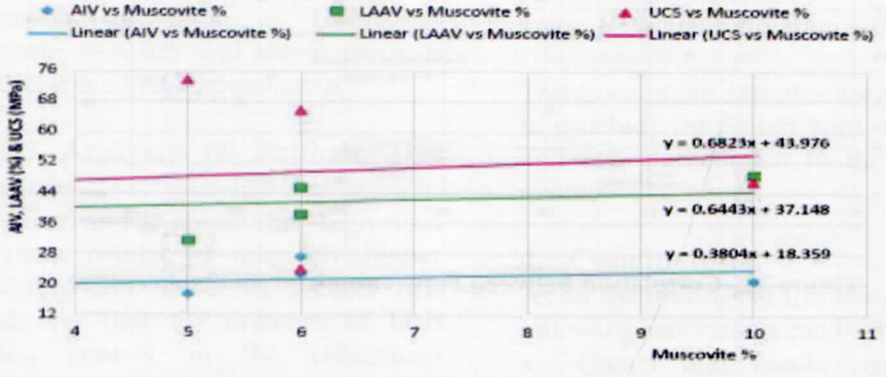

Figure 7 - Correlation between physical test results and Muscovite percentage

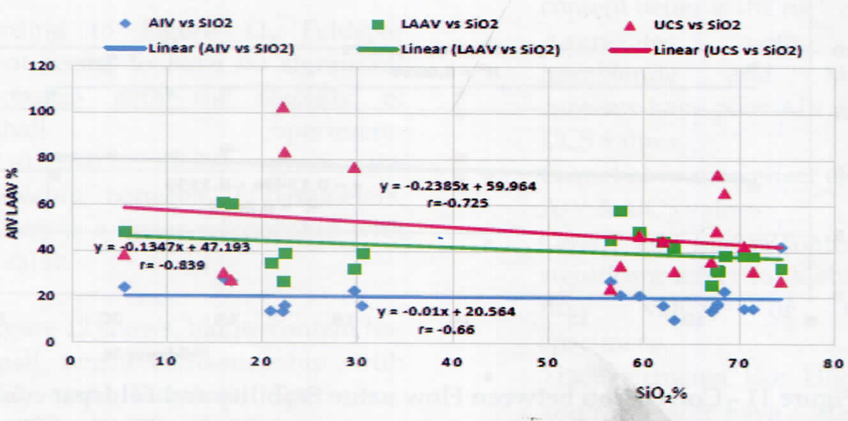

Figure 8 - Correlation between AIV, LAAV and Silica content of aggregates

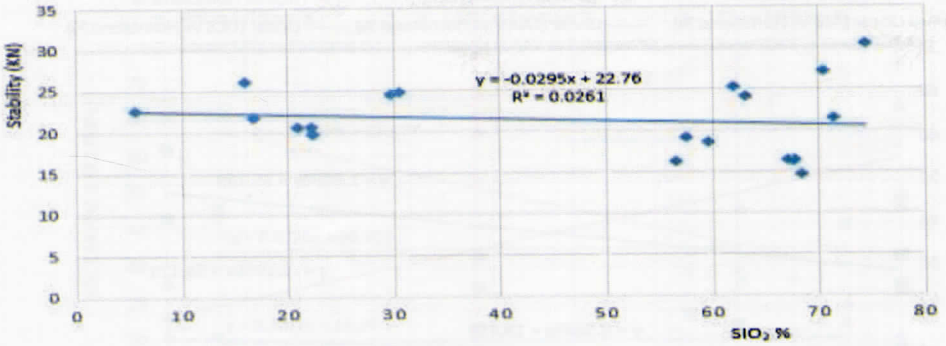

Figure 9 - Correlation between Stability and SiO2 percentage

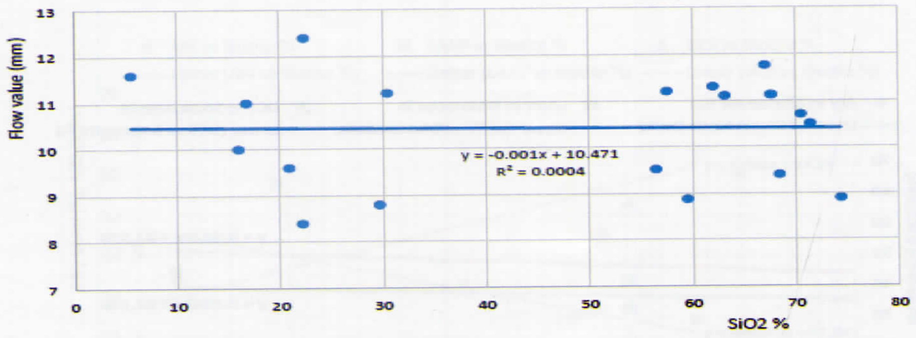

Figure 10 - Correlation between Flow value and SiO2 percentage

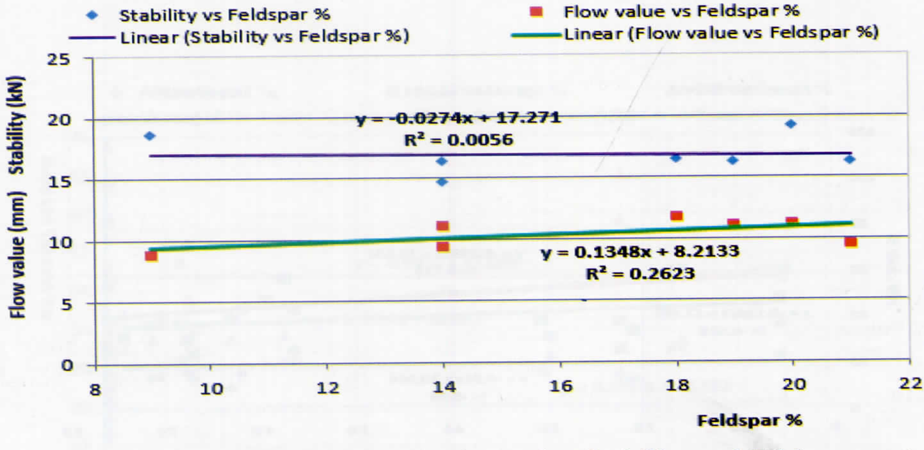

Figure 11 - Correlation between Flow value Stability and Feldspar content

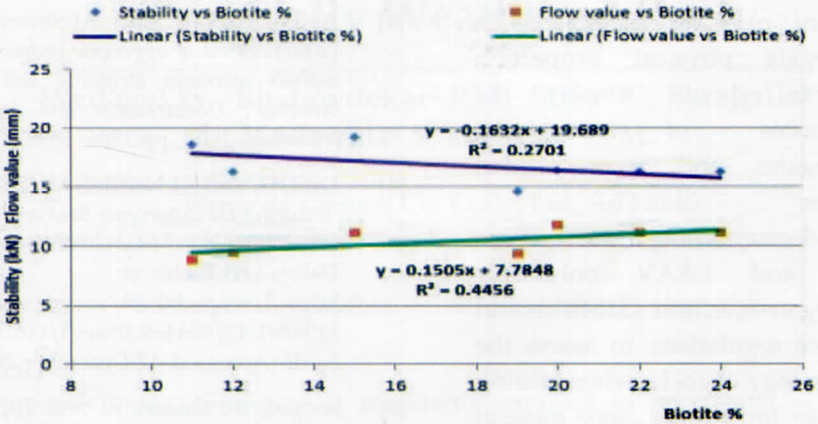

Figure 12 - Correlation between Flow value, Stability and Biotite

The relationship with LAAV and the quartz percentage of aggregates can be expressed as y= 3.2266x-138.76. Pearson correlation of LAAV vs Quartz is -0.325 and the P value is 0.018. It is a Weak relationship.

3.2.3 Analysis of Asphalt Test Results

Figure 9 and 10 shows that high silica content results in relatively higher stability and low flow values. This indicates that the presence of high silica content in the constituent aggregates will increase the strength and lower flexibility of asphalt pavements.

According to Figure 11, Feldspar content seems to have no significant relationship with the stability of Marshall Specimens. y= -0.0274x+ 17.271 gives the relationship between 2 parameters. But there is a linear relationship with flow value.

As Figure 12 shows, biotite content has a small negative relationship with stability of Marshall Specimens. y = 0.1632x+19.689 gives the relationship of Biotite and stability. But there is a moderate linear relationship with flow value. R^2 value of equation is 0.45.

Therefore, more samples are required to conclude the Significance of Biotite and Feldspar content to the asphalt quality.

4. Conclusions

As for the findings of this research, the following conclusions can be made.

- Quartz and Biotite content of aggregates has a significant effect on AIV, LAAV & UCS values. Higher the quartz and Biotite content better is the rock quality
- Aggregates with higher hornblende and Muscovite contents have poor AIV, LAAV & UCS values.
- Garnet shows no effect on LAAV, AIV & UCS values
- Quartz and Biotite content has a significant effect for stability and flow values of Marshall specimens.
- Trace elements like Hornblende and Muscovite have a slight effect in stability reduction.

5. Recommendations

- As Quartz, Feldspar and Biotite content plays a major role in aggregate physical properties, quarries should display the properties of supplying aggregates and recommended values.
- Local construction industry uses AIV and LAAV only for aggregate selection. GSMB should enforce regulations to assess the mineralogy of rocks when issuing licenses for mining since mineral content has a significant effect on aggregate quality
- As trace element analysis was done with minimum number of samples, for ensure more accurate results, use of more samples and time representing the population.

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