Effect of Physical and Mineralogical Properties of Aggregates on Strength and Durability of Asphalt Concrete

Bastion Pulle GS, Chandrapala SWTD, Rangana KHVG, *Chaminda SP, Jayawardena CL and Premasiri HMR

Department of Earth Resources Engineering, University of Moratuwa, Sri lanka
*Corresponding author – chamindaspc@yahoo.com

Abstract

Asphalt is a mixture of aggregates, binder and filler. The performance of an asphalt matrix mainly depends on the characteristics of its constituents along with the quality of construction process. As 94-95 percent of the total weight of asphalt matrix consists of aggregates, the performance of the mixture is greatly affected and influenced by the properties of aggregates. In the local asphalt industry, aggregates used to produce asphalt concrete, are tested and approved for the application only by evaluating physical parameters such as LAAV, AIV, and shape tests. In this research, mineralogical properties of aggregates have been systematically analysed along with the respective physical and asphalt properties. Crushed aggregates and lump samples were collected from a number of metal quarries and asphalt plants, representing rock types from three major geological complexes; Wanni, Highland and Vijayan of Sri Lanka. Tests were carried out to evaluate physical and mineralogical properties of aggregate and Marshall stability and flow values of asphalt mixture. The suitability of aggregates for asphalt pavement construction were discussed using the test results. Findings of the research proposes to consider the collective influence of both physical and mineralogical properties of aggregates when selecting competent materials for asphalt concrete manufacture.

Keywords: Aggregate physical properties, Aggregate chemical compositions, Asphalt concrete

1. Introduction

The road construction industry of Sri Lanka has shown a steady growth over the past few years. At present, there are many on-going highways and other road construction projects. This situation has arisen due to urbanization, resettlement and growth of economy. As a result, the demand for road construction materials has shown a considerable increase.

According to the national road statistics provided by Sri Lankan Road Development Authority, in 2016, Sri Lanka has 12,379 km of national highways and 169.13 km of expressways and many more to come in the future. Almost all these roads are paved using asphalt concrete. Also, road network of Sri Lanka is very dense and laid-out providing connectivity to the country's population and centers of economic activity. The network's density is among the highest in Asia [1].

Therefore, the requirement to have a maximum useful life of asphalt concrete roads is essential. In order to achieve the maximum strength and durability of roads, quality control of construction material and manufacturing process are very much important and it is a major concern in industry today.

Primarily, asphalt concrete is a mix of bitumen and a blend of densely 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].

Asphalt-aggregate interactions are important in the adhesion of asphalt cement to aggregate because the asphalt must adhere to the aggregate for the adhesive binding action of asphalt to occur. Many factors influence the strength and durability of the bond between asphalt and aggregate such as environmental and traffic factors, water intrusion, chemical and physical characteristics of aggregates, etc. These can cause failure of bond between the asphalt and aggregate and causing asphalt to separate or strip from the aggregate, leaving the aggregate loose without a binder to keep the aggregate particles and, hence, the pavement together, reducing overall strength and durability of asphalt concrete [3].

Present market has many low-quality construction materials such as poor quality aggregate, bitumen, cement etc. and many unskilled workers are employed at many road construction sites in Sri Lanka. According to Road Development Authority (RDA), Sri Lankan government expend huge amount on road maintenance. Thus, the quality of asphalt concrete plays a major role in this context. For optimizing the quality of ultimate asphalt concrete mixtures and the durability of asphalt pavements, the influence of the quality of aggregates should be addressed.

The main objective of this research is to assess the effect of physical and mineralogical properties of rock aggregates on the strength and durability of asphalt concrete.

This study involves the collection of a number of representative aggregate samples which are currently being used in the process of manufacturing asphalt in Sri Lanka. The locations are illustrated in Figure 1.

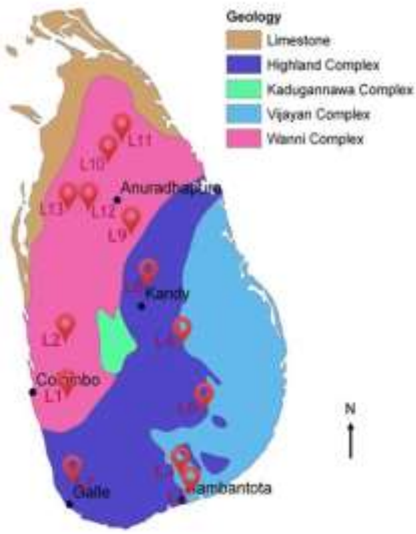

Figure 1 - Distribution of sampling locations

A series of tests have been carried out to determine both the physical and mineralogical properties of aggregates and quality of asphalt in this study. The test results were used to carry out performance analysis by means of statistical linear regression analytical tools.

2. Methodology

The research methodology consisted mainly of a preliminary data analysis, field data gathering and analysis, sample collection, testing, results analysis and the interpretation of relationship between physical and mineralogical properties of aggregates and the quality of asphalt concrete with recommendations for the selection of suitable source rocks.

2.1 Preliminary Data Analysis

Prior to commencing of field visits, sample collection and testing, preliminary data gathering and analysis were conducted. Here, the already available research data related to asphalt production, asphalt paving, design considerations, properties of aggregates which affect the bonding between asphalt and aggregates, asphalt aggregates interactions in asphalt pavement, testing of asphalt for its durability assessment and testing of aggregates to assess its properties were received. The knowledge gap in the local industry to identify most suitable source rock for asphalt cement manufacturing was evaluated.

2.2 Sample Collection

This stage of the study was initiated with the collection of data from the Geological Survey & Mines Bureau, Sri Lanka (GSMB) related to quarries in largest three geological complexes in the country. Samples were collected from five different locations, representing different rock types in this year. The details of sampling locations are given in Table 1.

2.3 Laboratory Testing

Physical Properties

Bulk Specific Gravity, Uniaxial Compressive Strength (ASTM D7012 – 14), AIV (IS:2386 - PART IV-1963) and LAAV (ASTM C131), Water Absorption (ASTM C127 – 15), and Aggregate Soundness (ASTM C88 – 13) tests were carried out in order to evaluate the physical properties of aggregates.

Mineralogical Properties

Silica content by digestion with HF acid (ASTM C1567 – 13), and Iron content using colorimetric spectrophotometry (ASTM D1691 – 12) were determined.

Table 1 - Description of sampling locations

Sampling Ref. No.	Metal Quarry	GPS Coordinates	
		Easting	Northing
L1	Boulder Mix, Meepe	06^{0} 51′ 36″	80^{0} 05′ 59″
L2	Senok Mining, Kotadeniyawa	07^{0} 17′ 01″	80^{0} 05′ 19″
L3	Southern group construction, Hambanthota	06^{0} 18′ 58″	81^{0} 03′ 16″
L4	CECB, Mahiyangana	07^{0} 15′ 28″	81^{0} 02′ 42″
L5	CML, Hambanthota	06^{0} 09′ 07″	81^{0} 06′ 41″
L6	Darme metal crusher, Yudaganawa	06^{0} 46′ 45″	81^{0} 13′ 21″
L7	K.D.A. Weerasinghe, Kahatapitiya	06^{0} 12′ 45″	80^{0} 08′ 10″
L8	Crusher plant, Moragahakanda	08^{0} 14′ 43″	80^{0} 52′ 30″
L9	Maga Neguma, Kakirawa	08^{0} 09′ 15″	80^{0} 04′ 03″
L10	Punawa metal quarry, Punewa	08^{0} 36′ 27″	80^{0} 26′ 46″
L11	Access, Vauniyawa	08^{0} 46′ 01″	80^{0} 33′ 01″
L12	Oththappuwa metal quarry	08^{0} 15′ 12″	80^{0} 16′ 10″
L13	Dammika metal crusher, Saliyawewa	08^{0} 05′ 24″	80^{0} 02′ 23″

Asphalt Tests

Under asphalt tests, standard test method for Marshall Stability and Flow of Asphalt mixtures (ASTM D6927 – 15) was carried out in order to determine the bulk density, stability and flow values of Marshall Asphalt specimens. The Mix Design used for preparing asphalt concrete specimens is presented in Table 2.

Table 2 - Mix specification for wearing course [Source: Research & Development Division, RDA, Sri Lanka Rehabilitation & Improvements to Colombo - Kandy Road from Kadawatha - Nittambuwa (23 km)]

Sieve Size (mm)	Percentage Passing (%)	Percentae Retaining (%)	Retained Weight (g)
25	100	0	0
19	99	1	12
9.5	74	25	300
4.75	50	24	288
2.36	38	12	144
1.18	30	8	96
0.6	24	6	72
0.3	17	7	84
0.15	10	7	84
0.075	4	6	72
Filler	0	4	48
Total	-	-	1200
Optimum bitumen content by weight of mix (%)			4.7

3. Results and Discussion

3.1 Results

Results obtained from physical tests are tabulated in Table 3 – Table 4

Table 3 - Summary of Physical test results

Location	Bulk Specific Gravity	UCS (MPa)	AIV (%)	LAAV (%)
L1	2.75	-	16.16	38.76
L2	2.8	-	13.87	34.57
L3	2.93	83	16.33	38.72
L4	2.76	38	24.01	47.90
L5	2.76	103	13.62	26.50
L6	2.93	27	26.84	60.45
L7	2.69	76	22.69	32.01
L8	2.75	31	28.02	60.87
L9	2.64	43	15.33	38.48
L10	2.88	32	15.37	38.08
L11	2.75	32	10.38	42.15
L12	2.57	45	16.64	44.67
L13	2.56	27	42.22	32.71

Table 4 - Summary of water absorption and soundness test results

Location	Water Absorption (%)	Soundness (%)
L9	2.145	1.72
L10	3.077	2.17
L11	2.720	1.65
L12	2.774	2.78
L13	2.031	2.12

Results obtained from the chemical tests have been tabulated in Table 5.

Table 5 - Summary of chemical analysis test results

Location	SiO_2 Content (%)	Iron Content (%)
L1	30.49	6.08
L2	20.92	3.96
L3	22.38	5.55
L4	5.56	10.37
L5	22.20	6.05
L6	16.78	5.11
L7	29.68	6.18
L8	15.99	2.49
L9	70.53	1.46
L10	71.45	1.88
L11	63.18	1.52
L12	62.02	2.66
L13	74.40	1.18

Table 6 - Summary of asphalt test results

Location	Avg. bulk density (g/cm^3)	Avg. stability (kN)	Average flow value (mm)
L1	2.47	24.80	11.2
L2	2.46	20.66	9.6
L3	2.53	19.72	12.4
L4	2.53	22.59	11.6
L5	2.47	20.67	8.4
L6	2.47	21.73	11.0
L7	2.41	24.52	8.8
L8	2.47	26.17	10.0
L9	2.40	27.22	10.7
L10	2.41	21.41	10.5
L11	2.55	24.14	11.1
L12	2.44	25.22	11.3
L13	2.37	30.56	8.9

3.2 Discussion

According to Indian Standards, the aggregates which were used for surface dressing may have the absorption values between 0.1 to 2.0 percent. On the other hand, they may possess a value of 4.0 percent when they are used in base course. If the absorption value of aggregate is higher than 2%, then it should be tested for soundness to permit to be used in course. All the values result from water absorption test were higher than 2%. However, the values obtained from soundness test were within the maximum permissible limit of 15% [4].

Figure 2 shows AIV%, LAAV% variation with silica content in previous year study and figure 3 shows variation between same variables in this year study carried out. According to statistical regression analysis, respective AIV and LAAV values have decreased significantly with the increase of silica percentage. The variation of the LAAV value with silica content in this year results are same as in previous year with a strong negative linear correlation. However, AIV% vs. silica content shows a moderate positive correlation in this year results.

This indicates that, high silica contents will be an added advantage to occupy relatively high resistance over abrasion of the ultimate asphalt pavements.

Figure 4 shows higher water absorption results in relatively low stability values. Because the portion of bitumen which is absorbed is not available for binding the aggregate particles together in the asphalt paving mix.

Figures 5 and 6 show that high silica content results in relatively higher stability and low flow values. According to the regression analysis, strongest correlation is shown by this year flow values. This indicates the presence of a high silica content in the constituent aggregates will increase the strength and lower flexibility of asphalt pavements.

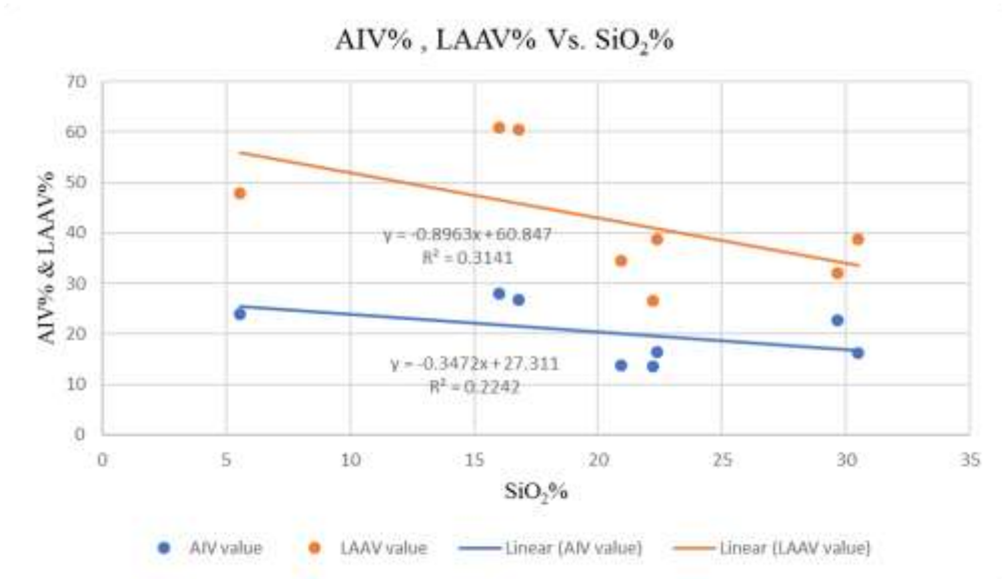

Figure 2 - Variation of AIV%, LAAV% Vs. Silica Content in the previous previous year

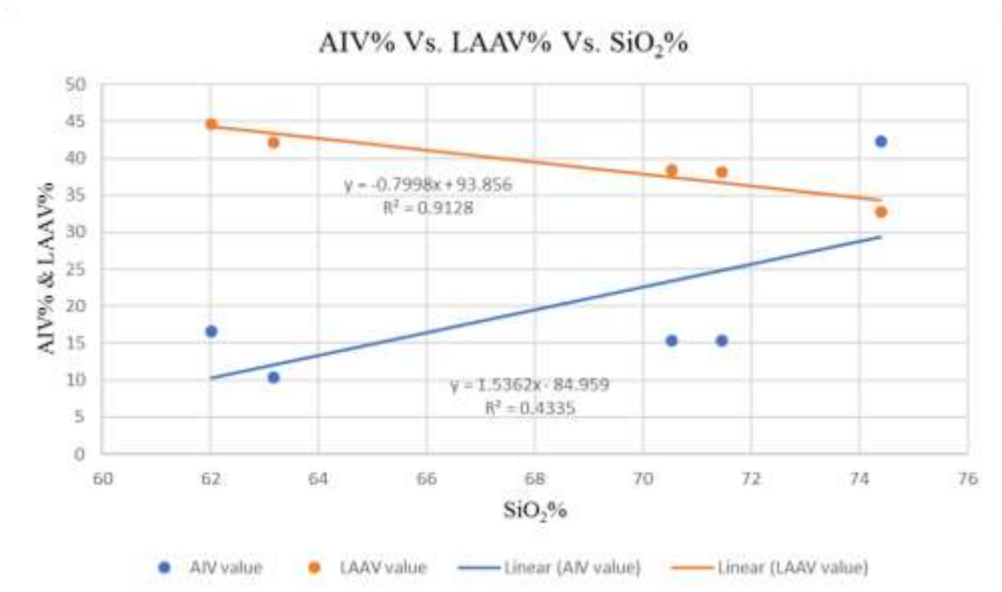

Figure 3 - Variation of AIV%, LAAV% Vs. Silica Content in this year

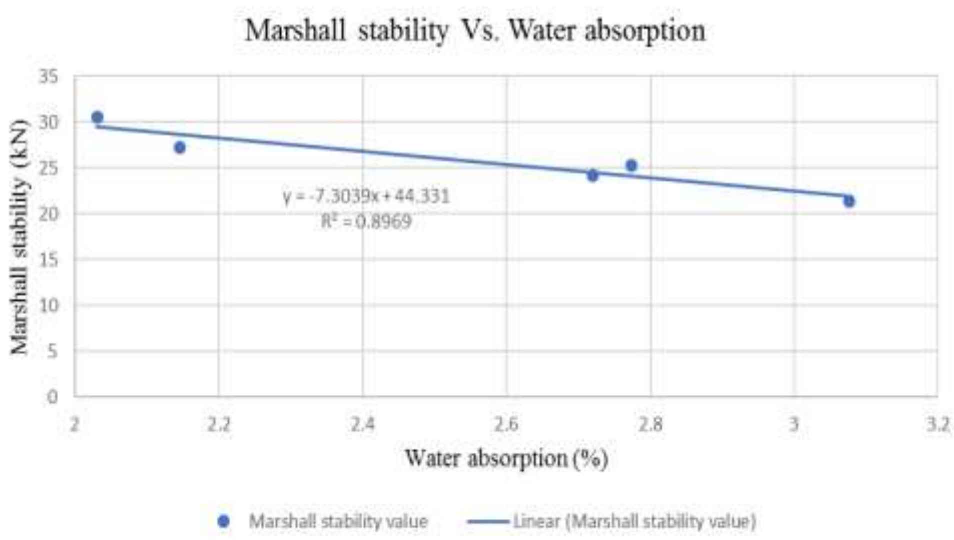

Figure 4 - Variation of Marshall Stability Vs. Water Absorption

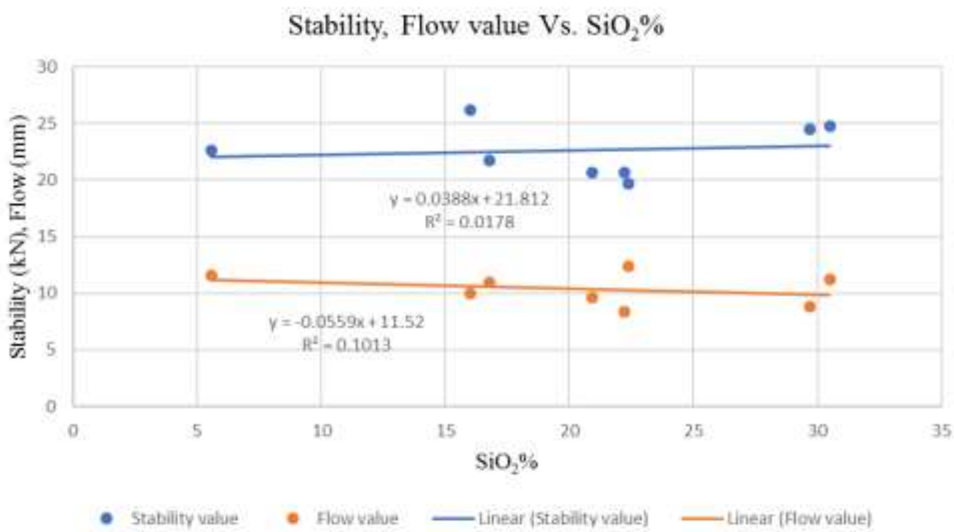

Figure 5 - Stability, Flow value Vs. SiO_2 Content in the previous year

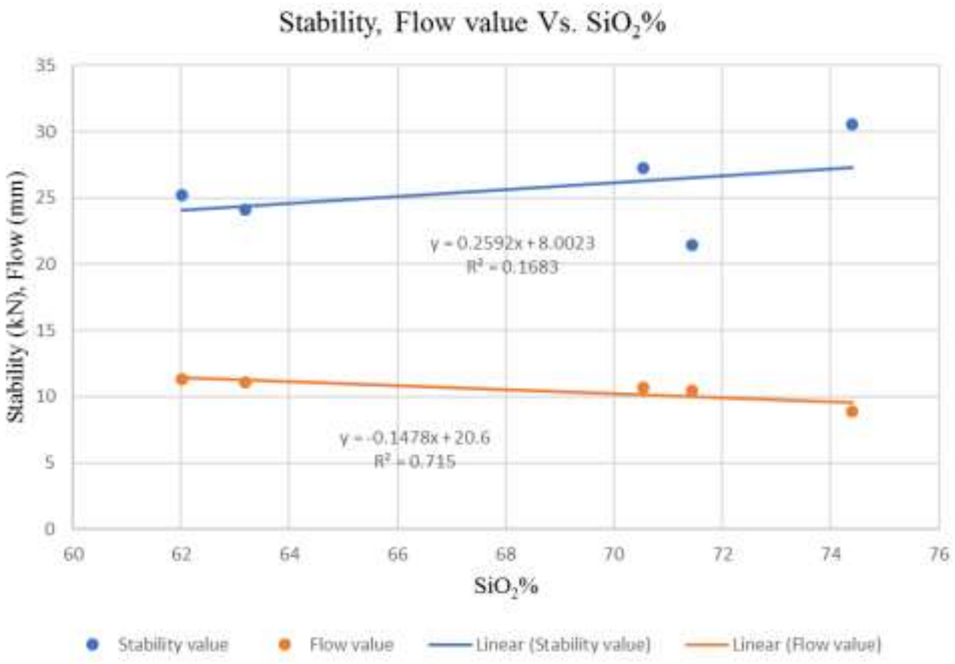

Figure 6 - Stability, Flow value Vs. SiO_2 Content in this year

Regression Analysis

Regression analysis were conducted to evaluate correlation between mineralogy and resultant physical properties of aggregate, stability and flow value of final mixture. Also, it is used to evaluate how physical properties of aggregates affect on the stability and flow value of asphalt concrete.

AIV, LAAV and the Stability

The Root Mean Square value, R for the analysis conducted for AIV, LAAV and the stability of asphalt concrete is 0.8556. This indicates that the model explains 85.6% of the variability of the response data around the mean. So, this model is acceptable. The "r" value obtained is 0.9250. Thus, there exist a strong linear relationship between AIV, LAAV and the stability.

AIV, LAAV and the Flow Value

R value for the analysis conducted for AIV, LAAV and the Flow Value of asphalt concrete is 0.99281. This indicates that the model explains 99.3% of the variability of the response data around the mean. Hence, this model is acceptable. The obtained "r" value is also equal to 0.9964. Thus, there exist a very strong linear relationship between AIV, LAAV and the stability.

SG, UCS, AIV, LAAV and the Stability

R value which was obtained by the analysis of all the physical properties tested and the stability of asphalt concrete was 1. Thus, there exists an ideal linear relationship when taken collective influence of these parameters.

SG, UCS, AIV, LAAV and the Flow Value

R square value which was obtained by the analysis of all the physical properties tested and the flow value of asphalt concrete was equal to 1. Thus, there exists an ideal linear relationship when collective influence is considered.

4. Conclusions

- Silica content of rock aggregates has a significant effect on LAAV value and relatively lesser effect on AIV value. Generally, high silica contents result in low AIV and LAAV values, and vice versa.
- Aggregates with lower absorption values show higher stability values in ultimate asphalt concrete design.
- Aggregates with higher silica content, show higher stability values in the ultimate mixture of aggregate and bitumen, resulting in high rigidity in asphalt concrete.
- In accordance with the regression analysis results, silica content of rock aggregates has a significant effect on flow value of the final mix. It shows that aggregates consisting of high silica content, show relatively low flow values and thus relatively a low flexibility can be experienced in the resulting asphalt concrete.
- The regression analysis was clearly indicated that there is a strong correlation between combined effect of AIV, LAAV and the stability and flow values of final asphalt mixture.
- It also shows that there is an ideal linear relationship between collective action of SG, UCS, AIV, LAAV and stability and flow value of Marshall design.

5. Recommendations

- As silica content of rocks directly affects the corresponding AIV, LAAV and the stability values, carrying out of a silica analysis prior to planning of any mix design or a selection of source rock to produce aggregates is essential.
- Consideration of physical or chemical properties individually, in making conclusions regarding manufacturing specifications of asphalt mix designs might mislead the competent judgment. Therefore, considering the collective influence of both physical and chemical properties on the quality of asphalt is essential.
- As these results are based on a minimum number of samples, for more accurate regression analysis, it is suggested to test more representative samples in the future investigations.

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