USE OF GLASS FIBERS IN STONE MASTIC ASPHALT FOR THIN ASPHALT SURFACING

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Abstract

Sri Lankan road construction sector is dealing with ever depleting construction material problems, especially finding good quality aggregate has become more difficult for projects over the past few years. The accelerated development demands a lot of natural resources and the extraction of resources like aggregate on a mass scale pose a significant threat to the environment. Using the available resources sparingly and optimally is the way forward to brace the scarcity of construction material we are about to face.

There are many projects in progress to upgrade low volume roads. But the designs are done using a 50mm asphalt wearing course, which is a very conservative approach given the traffic movements of the roads are very much limited. For the traffic levels in such roads, by using a thin asphalt layer which is between 25mm-35mm the same function could be achieved while cutting down construction costs for the pavement significantly. The aim is to adopt a mix that can be laid in thin layers, which performs well in Sri Lankan conditions.

Therefore a Stone Mastic Asphalt(SMA) mix design was adopted, and using 60-70 bitumen and added glass fiber laboratory trials were carried out to find the optimum bitumen contents, optimum fiber contents and fiber lengths . Glass fiber was selected as the fiber due to good bitumen coating ability and availability locally. Then indirect tensile strength test was carried out for Marshalls casted in order to observe the structural properties behavior when fibers are incorporated

By analyzing the results, it is concluded that a successful mix which complies with the standard can be achieved with a mix with 6.5% bitumen to weight and by adding 1.6% to 2% of glass fiber to the mix.

Keywords: Thin Asphalt Pavements, Low Volume

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Table of Contents

Declaration i

Abstract ii

Acknowledgment iii

Table of Contents iv

List of figures v

List of Tables vi

List of Abbrevaitions vii

1 Introduction 1

1.1 Background 4

2 Literature review 5

2.1 Stone Mastic Asphalt(SMA) 8

3 Problem Statement 10

4 Objective 11

5 Research Scope 12

6 Methodology. 13

6.1 Mix Selecting Criteria 13

6.2 Incorporation of fibers 19

6.3 Indirect tensile strength 20

7 Results 21

7.1 With Fiber 24

8 Discussion 31

9 Conclusion 34

10 References 35

List of figures

Figure 1.1:A low volume road which is selected to be upgraded 1
Figure 1.2:Gravel road in the rainy season 2
Figure 2.1:Strcture of Dense grades asphalt concrete and SMA 9
Figure 6.1: SMA 10N Graddation.. 14
Figure 6.2:SMA 10H Graddation... 15
Figure 6.3:SMA 7N Graddation... 15
Figure 6.4:Classified aggregate.. 16
Figure 6.5:The average passing percentage 17
Figure 6.6:Mixed Aggregate 18
Figure 6.7:Mixing with bitumen 18
Figure 6.8:Compaction of the Marshalls.. 18
Figure 6.9: The glass fibers which were cut and prepared for mixing...................... 19
Figure 6.10:Indirect tensile test.. 20
Figure 7.1:Stability vs Bitumen Content Variation.. 21
Figure 7.2:Air Voids Content vs Binder Content 22
Figure 7.3:Flow vs Binder Content Variation.. 23
Figure 7.4:Vma vs Binnder Content 23
Figure 7.5:Air Voids vs Fiber Content... 25
Figure 7.6:Flow vs Fiber Content 26
Figure 7.7:Vma vs Fiber Content... 26
Figure 7.8:Stability vs Fiber Content 28
Figure 7.9:Air Voids Content vs Fiber content.. 28
Figure 7.10:Vma vs Fiber content.. 29
Figure 7.11:indirecrt tensile strength variation with fiber content............................ 30

List of Tables

Table 6.1:Grading specification requirement.. 13

Table 6.2:Passing and retaining a percentage of aggregate 17

Table 7.1:Marshall test results 21

Table 7.2:The specification limits.. 24

Table 7.3:Marshall test results 25

Table 7.4:Marshall properties of 5mm fiber mixes... 27

Table 7.5: Marshall properties of 10mm fiber mixes.. 27

Table 7.6:Indirect tensile strength of fiber mixed Marshalls 30

Table 8.1:Cellulose fiber vs Glass fiber.. 32

List of Abbreviations

Abbreviations	Description
AC	Asphalt Concrete
ESA	Estimated Number of Standard Axels
SMA	Stone Mastic Asphalt
VA	Air Void
VMA	Voids in Mineral Aggregate

1 Introduction

The quality and connectivity of low-volume road networks, which are mostly scattered across rural communities, are identified as a critical component that directly affects the community's quality of life. The roads promote access to economic and social services such as schools, hospitals, farms and markets and thereby increases agricultural income and productive employment opportunities. The accessibility is directly related to the land value of the area and it is also identified as a critical ingredient in ensuring sustainable poverty reduction.

In the past, most of these roads remained as unpaved gravel roads where the conditions of the roads deteriorated significantly during the monsoon season. The gravel roads offered the cheapest alternative with the minimum capital investment. But when the whole life cycle cost is considered due to the frequent maintenance they need, the cost of maintenance can accumulate and add up, totaling in large sums. Compared to the unpaved gravel road, the lifecycle cost of construction and operating a paved road can be cheaper. Then after under the local authorities, the roads were surfaced using metalling and tarring, and concreting. In the recent past, a

Figure 1.1:A low volume road which is selected to be upgraded

large number of these low volume roads were upgraded into asphalt concrete surfaced roads from foreign and local bank funds. It is a popular economic theory that improving mobility by improved roads alone boosts the local economies considerably; adhering to this concept, the policymakers tend to focus on t improving rural roads using high quality and expensive asphalt concrete paving.

Since there have been many studies carried out in the world about the structural requirements and the behavior of asphalt under low traffic conditions, these researches lead to the use of thin asphalt surfacing. The use of a thin asphalt paving leads the way to cut costs and deliver an acceptable, cost-effective quality solution to the upgrading of these low-volume roads. Thus paving thin asphalt layers comes into light.

With the recent high focus on upgrading low-volume roads to paved roads, there are many projects currently being implemented which cumulatively account for the upgrading of thousands of kilometers of rural roads. The policy to upgrade low-volume roads seems to be unchanged with government changes and as a result, there are a lot of low volume roads waiting to be upgraded in the future. Given the circumstances, it is identified that the resource demand has risen drastically due to the great extent of roads which are being constructed.

Thin asphalt layers are commonly used in low volume roads around the world these pavements are mostly used in sparsely populated areas. It is common to have an

Figure 1.2:Gravel road in the rainy season

upper bituminous layer that is about 10mm-40 mm thick over one or two well compacted unbound granular material road bases over the subgrade. The bearing capacity of the thin asphalt pavement predominantly comes from the roadbase. The function of the bituminous layer is waterproofing and provides a smooth riding surface, whereas the contribution to the bending stiffness of the pavement is low. This design of thin asphalt layers can be done empirically and mechanistically. The pavement design practice of these types of pavements is highly country-specific and suitable adaptations should be taken into consideration, taking weather, rain, traffic characteristics and geometry of the region into consideration.

(Low Volume Roads) Has elaborated that the cost of graveling extends further beyond just material and construction costs. The overexploitation of resources can harm the ecology of the area in a harmful way. Since the scarcity is already threatening the industry and the cost of quality gravel is rising, it is better to look for an alternative. The gravel roads also cause severe dust pollution, which negatively affects the lives of those who live closer to the unpaved roads. And it can also cause reduced yield in crops that are located on either side of the unpaved roads due to the dust cover.

The gravel roads need a lot of maintenance and regraveling should be done in each and every 2-3 years span and the local authorities allocates a considerable amount of funds for the regraveling of the roads. Paved roads need minimal maintenance due to the low traffic volumes these roads carry and could be serviceable for 10 years without any significant maintenance. If the improvement to the quality of life and other indirect benefits are accounted for, though the initial capital requirement is very high, paving these roads saves a lot of time and money during their lifetime.

1.1 Background

Sri Lankan roads sector has given attention to developing roads that connect rural communities in the past few years. Many high-value projects are being carried out to fulfill this goal. The aim is to uplift the lives of remote communities by improving road connectivity. Most of these roads are paved with asphalt concrete and some are constructed as rigid pavements. When looking into the motorized movements on these roads, it is found that these roads aren't carrying significant traffic. The heavy vehicle movement is minimal on these roads. Technically a low-volume road is identified as a road that only carries few vehicles per day, and the heavy vehicle movement is also very much limited (between 5% to 10%) in these types of roads. Typically, if a road carries less than 300 vehicles a day and it only accumulates far less than 1 million equivalent standard axels during the design life.

In this research, we are looking into the possibility of using thinner asphalt layers that replace the 50mm asphalt concrete layer laid using 20mm aggregate mix design.

Figure 1.3:Gravel road in Rasnayakapura-Nikaweratiya

This will, in return, save a lot of material time and money. In this research, we focus on developing a mix that is able to satisfy the structural requirements for low volume roads retaining the surface quality and durability of a 50mm asphalt concrete mix.

2 Literature review

(Guidelines for the use of thin layer hot mix asphalt wearing) Identifies the purpose of a thin asphalt layer is to

1. Function as a stress interface between the road base and the wheel loads, which carries moderate light vehicle traffic. The function of the asphalt concrete layer is to further provide protection to the base course against traction and braking forces exerted by vehicular movements.

2. The contribution of thin asphalt pavements to the pavements' structural capacity is not the main focus. Further, the thin asphalt layer should be able to have enough resilience to provide a durable, lasting surface that is less susceptible to transient deflections. The thin asphalt layer is also expected to act as a layer that inhibits water from penetrating to subsequent unbound layers where water ingress may lead to plastic deformation.

4. And asphalt concrete layer, in general, offers high ride quality and sufficient skid resistance. Pavement layers such as this are referred to as functional asphalt layers.

(Falla & Oeser, 2016) In their journal Advances in Transportation Geotechnics
While developing a mechanistic-empirical design procedure, especially for low volume roads, it is found that response of thin asphalt pavements under low traffic conditions showed that durability of pavements which are less than 50mm thickness are promising. This is satisfied, provided that the design is done considering the nonlinear behavior of unbound granular material in the base course. It is also decided that the granular material which is subjected to loading should be modeled using nonlinear stress-dependent models.

The sub-base exhibits a stress-dependent behavior while the scale of stresses exerted on the subbase is comparatively smaller than that applied on the base course. Therefore, in mechanistic-empirical analysis practice, nonlinear material behavior into stiffness computations for the subbase is less significant than for the base course in thin asphalt pavements.

The conclusion is that the base course construction should be done using high-quality material with strict quality control and quality assurance. The base should be constructed with crushed rocks, and in the Sri Lankan context, the road base is already built using crushed rocks. Stabilizers also can be used to achieve desired properties when suitable materials that comply with the standards are not readily available.

It is emphasized from this paper that the gradation of the base course plays an important role. In this regard, coarse graded aggregate has the ability to increase layer bearing capacity if the overall material used has a proper grading. And it also suggests narrower grading bands in order make sure the material gradation variations stay minimal since then more homogeneous material can be expected to arrive at sites.

The wearing course of thin asphalt pavement can be even a chip seal with a thickness between 10 to 40mm. This layer acts and behaves as a membrane with no bending stiffness. According to this paper, the primary mode of failure which is more likely to happen is raveling cracking. Mixes with high resistance to plastic deformation and increased flexibility to bear a significant elastic deformation should be employed to prevent failures. The aggregates used for them mixes should be of high quality and also, the aggregates must have high resistance to fragmentation, wear and polishing. These properties should be there to achieve sufficient grip and ride comfort.

(Buddi, Prasanthi, & Srikanth, January 2015) Have elaborated about the fiber-reinforced materials from their article. According to their article, engineering materials are classified into three broad categories, which are metals, ceramics and polymers. The materials which are formulated combining two or more of these materials are called composites. In composites, the phase, which is usually the stiffer and more robust, is identified as the reinforcement. The material which has lesser or low stiffness is identified as the matrix. The matrix is responsible for holding the reinforcement in the desired shape while the reinforcement improves the overall mechanical properties of the composite. The main mechanical parameters of a fiber-reinforced composite are specific strength and specific modulus, where the specific strength is defined as the ratio of tensile strength and specific modulus. The ratio between the tensile strength and the specific gravity is defined as the specific strength. The ratio between the modulus of elasticity to the specific gravity is defined as the specific modulus. The specialty of fiber-reinforced composites is that their properties can be altered as desired for each application. This is done by appropriate selection of the parameters like fiber orientation, volume fraction, the spacing between, fiber distribution in the matrix and the layer sequence. When using fiber-reinforced composites, the designers have the freedom of creating tailor-made material with desired properties for different requirements

Further (Busching & Antrim, 1968) states that the cellulose fibers are currently used extensively in gap graded asphalt mixes. The primary purpose of this is to achieve a high bitumen content in the mix without having excess bitumen drain down issues. The mix of fibers results in a more viscous mix with greater stability and high resistance to fatigue cracking than that of similar asphalt concrete mixes without fibers' addition.

The effect of fibers used as a modifier to asphalt was examined by (Serfass & Samanos, 1966).trials were carried out using rock wool, glass wool and cellulose fibers. It was concluded that fibers facilitate the incorporation of more and more bitumen to the mix, thus increasing the resistance to moisture cracking, aging and fatigue.

(Simpson, Oct 1994) conducted a study of modified asphalts using fibers, and he found the fibers caused the mixes to gain higher tensile strengths and resistance to cracking; it is found that the average fiber diameter and fiber length has a significant impact on the composite property.

(Mahrez, 2005) Conducted research using glass fibers in asphalt concrete mixes. From the research, it is found that the addition of fibers results in a decrease of stability and increase in the flow values, and most importantly, it has increased the air voids percentage of the mix. Further, it has been concluded that the glass fiber introduces the potential to resist structural distresses that apply when the road undergoes high traffic loading.

2.1 Stone Mastic Asphalt (SMA)

(Sehgal, 2017) Stone Mastic Asphalt (SMA) is designed to have exceptional rutting resistance properties compared to the conventional hot mix asphalt mixes. The stone mastic asphalt is a gap graded asphalt mix

SMA was developed by the Germans in the late 1960s & has been in use extensively in Europe since. The technology migrated to the USA in the 1990s, SMA has been ever since used as a wearing course in asphalt roads. SMA, over the years, has proven its use as a heavy-duty road surfacing mix. SMA can be identified as a gap graded highly rut resistant, robust and stable mix. It also has superior frictional properties. SMA mixes rely on the stone on and stone contact to withstand the forces exerted on the pavement, whereas in conventional fine graded mixes, the stone on stone contact between the aggregates is significantly less; therefore, the finer particles are subjected to heavy loads. The SMA has a large fraction of aggregates, which are retained by the 4.75 mm sieve. The concept of SMA can be pointed out as

1. Withstanding high loads while resisting high wear resistance by particle interlocking and high content of coarse aggregates.
2. A long-lasting pavement layer, which has a high resistance to cracking and raveling, could be achieved. The binder helps to form a void less mastic mortar, which helps fill the air voids between the coarse aggregate skeleton and bind together. It also facilitates a thick binder coat around the aggregates, and this results in long-lasting service life.
3. The stabilizing fiber additives ensure homogeneity and prevent binder drainage throughout in the mixing, transportation laying, and compaction phases.

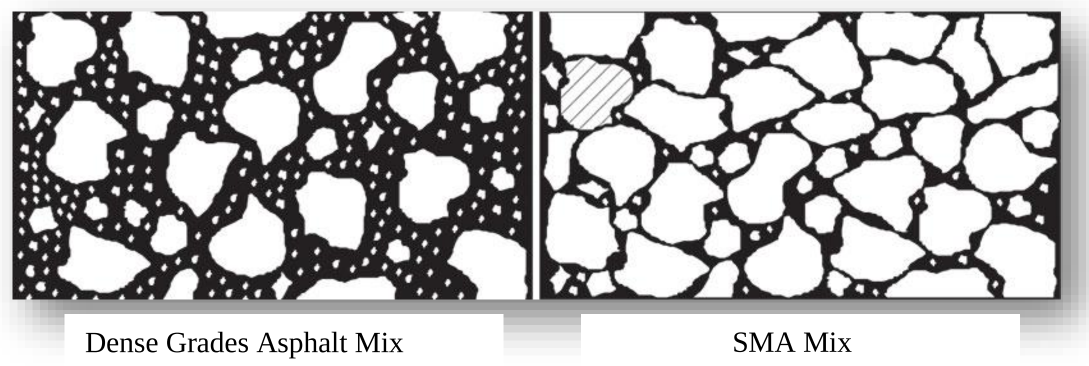


Figure 2.1:Strcture of Dense grades asphalt concrete and SMA

(K, OBE, de Brito, Mangabhai, & Qun Lye, 2016) in the book Sustainable Construction Materials, it is elaborated that bitumen and aggregate mix's adhesion properties are a crucial asphalt property that directly affects the service quality and lifetime of the pavement. Extensive researches have been carried out in this regard almost for a hundred years for now. But still, the adhesion mechanisms and modeling have to be improved further to analyze the behavior of bituminous mixes in detail. An indirect tensile test has been identified as a measure to understand the mixes fatigue properties. The asphalt concrete undergoes millions of repetitive loading and unloading cycles throughout its functional lifetime. Fatigue is the primary load-related failure that asphalt concrete undergoes. Fatigue cracks can expose the pavement's inner layers and allow water and air to penetrate into the mix. This process weakness the bonding between aggregates and cause premature oxidation of the binder. The penetrated water can reduce the sheer strength of inner pavement layers and can cause base failures.

3 Problem Statement

The 20mm asphalt mixes which are being used at the moment do not permit thinner paving than 40mm. The government authorities are going with the 50mm asphalt concrete layers for roads with minimal traffic and estimated number of standard axels(ESA) values. Since quality aggregate is becoming a scarce resource at the moment due to overexploitation, it is essential to optimize the use of resources according to the function of the road,

Stone Mastic Asphalt has is identified as a commendable alternative to conventional hot mix asphalt concrete. according to literature, it is evident that a stone mastic asphalt mix is well suited for laying thin asphalt surfacings. a suitable Stone Mastic asphalt mix have to be developed inorder to acess its capabilities.In this research a stone mastic asphalt mix is developed using glass fiber as the fiber additive.

The aggregate on aggregate contact provide better load-bearing capacity and superior rutting resistance capabilities to the pavement. And the stone mastic asphalt comes as a bitumen rich mix where bitumen content averages around 6%. This facilitates high film thickness, and high film thickness in return, facilitates good aging characteristics. It is also required to add a fiber material to a bitumen rich mix to make it more stable. The function of the fiber is to absorb some of the excess bituminous materials. The fiber also can improve the tensile properties of the material. In this research, an appropriate optimized mix with added fiber is developed.

4 Objective

The main objective of this research is to find the feasibility of using stone mastic asphalt mixes to pave thin asphalt surfacings on roads as required.The stone mastic asphall mixes inheritantly contain more bitumen than the ordinary hot mix asphalt mixes and therefore a fiber additive is used to stabilize the mix.In this research it is expected to find the usability of glass fibers as the fiber additive since glass fiber is available readily in abundance as a industrial waste.

The literature survey should be focused on the expected requirements needed to be fulfilled by a thin asphalt surfacing. When introducing thin asphalt layers, it should be able to withstand the forces and stresses generated by traffic movements.The mix should be able to have good aging and rutting characteristics.It is expected to find the function of the fiber in the mix and find whether any considerable enhancement or a deterioration is caused upon the structural capacity of the mix.

Details about the current practices followed internationally, and the knowledge base and data available regarding the scope should be seeked and gathered. Data and past experiences are vital to get the wholesome picture. Another objective is to analyze the thin asphalt application practices which are currently in use all over the world and gather data in order to be familiar with the concepts.

By taking the traffic and structural requirement and other identified factors into consideration, the main objective is to develop a durable, cost-effective thin asphalt surfacing. The developed mix is expected to replace the current practice of laying a 50mm wearing course where a thin asphalt surfacing is sufficient. And it is expected to function similarly with reduced construction costs. The aim is to carefully utilize locally available resources in order to form a successful mix

5 Research Scope

An in-depth literature review has been carried out regarding many aspects within the purview of thin asphalt pavements covering mechanistic-empirical approaches and various studies done around the world in this domain. The concerns arise when applying of thin asphalt pavements are studied.

A suitable proven base mix design had to be adopted at the start. Suitable mixes are extracted from VicRoads specification. VicRoads specification was mainly selected considering the vast experience and applications of thin asphalt mixes done in Australia. Extensive research and developments are being carried out regarding thin asphalt pavements in Australia

The mixes which were mentioned were reviewed at the beginning before selecting a mix to continue with the work. For these few parameters were used. The mixes should have 10mm as the maximum aggregate size in order to achieve the expected 25-30mm thin asphalt layer. The mix should be achieved using the existing hot bin materials from locally available sources. From this study, the SMA 10N mix appeared to be the most appropriate mix of all the mixes available. The mix was the easiest to formulate a satisfying blend from locally available aggregates extracted from asphalt plant hot bins.

The fiber addition is stated as a vital component in the specifications due to the mix's high bitumen content. And an alternative for the cellulose fiber additions, which is recommended in the specification, is sought. The mix's properties with changes with the fiber properties need to be analyzed since a new fiber is introduced, and those variations should be studied. To achieve a high-quality mix with superior properties, tests were done to find the behavior of structural parameters of the mix when fibers are introduced.

6 Methodology.

6.1 Mix Selecting Criteria

The SMA mixes from Vic roads 2018 under section 404(*table 6.1*) are adopted for this research. Vic roads specification is used since Australia has a wealth of knowledge in thin asphalt paving and has gained immense experience over the years. Therefore, the mix designs are used from the VicRoads and modified and altered to suit the Sri Lankan conditions.

Table 6.1:Grading specification requirement

Sieve Size AS (mm)	Percentage Passing (by mass)		
	SMA10N	**SMA10H**	**SMA7N SMA7H**
19.0	100	100	100
13.2	100	100	100
9.5	90-100	90-100	100
6.70	45-65	25-45	85-100
4.75	30-50	18-32	35-55
2.36	21-31	15-30	17-35
1.18	16-25	13-24	16-28
0.600	14-22	12-21	12-24
0.300	12-1 9	10-18	10-20
0.150	9-15	9-15	8-16
0.075	8-12	8-12	8-13

The mix designs from the specifications are used and an extensive study to identify the aggregate particle size distribution was done using the aggregate samples collected from various asphalt plants around the island. By the VicRoads specification the SMA 10N(10mm mix) mix is recommended for normal duty traffic and the SMA10H(10mm mix) is recommended for heavy duty traffic applications. The SMA7N and SMA7H are mixes with 7mm aggregates as the maximum aggregate size available.

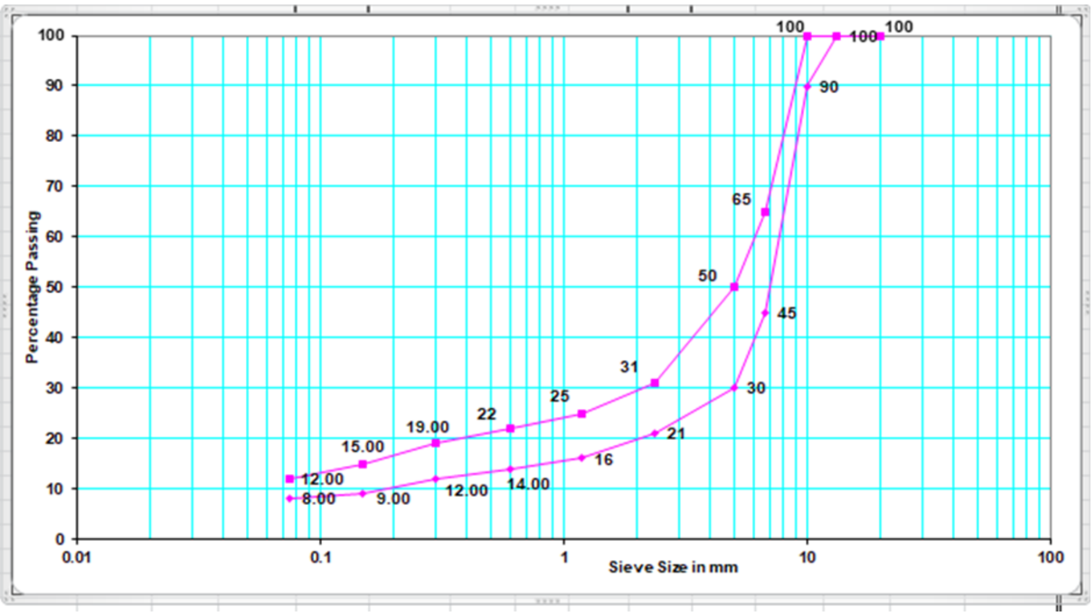


Figure 6.1: SMA 10N Graddation

By analyzing the grading nature of aggregate samples from different sources all over The country SMA 10N was the only grading band that could be achieved by mixing the available hot bin 1 and hot bin 2 aggregate material and suited for the anticipated traffic levels. SMA 10N aggregate gradations were selected as the base gradation for this research. In the Sri Lankan context, the sieve sizes 13.2mm and 6.7mm were not in use locally in laboratories and were not available locally. Therefore, the 12mm and 6.3 mm sieves were used instead for the aggregate screening process. The passing percentages were adjusted according to the new sieves introduced without having an impact on the original gradation. A new grading band with the newly introduced sieves was created. The grading bands of the other two mixes proposed from the specification are shown in *Figure 6.2* and *Figure 6.3*.

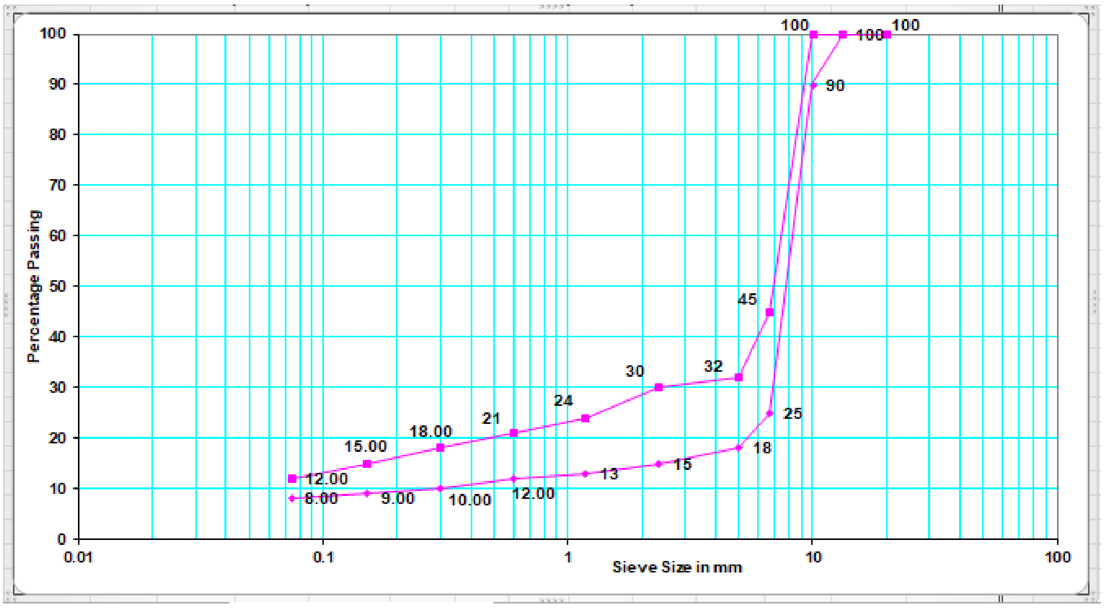


Figure 6.2:SMA 10H Graddation

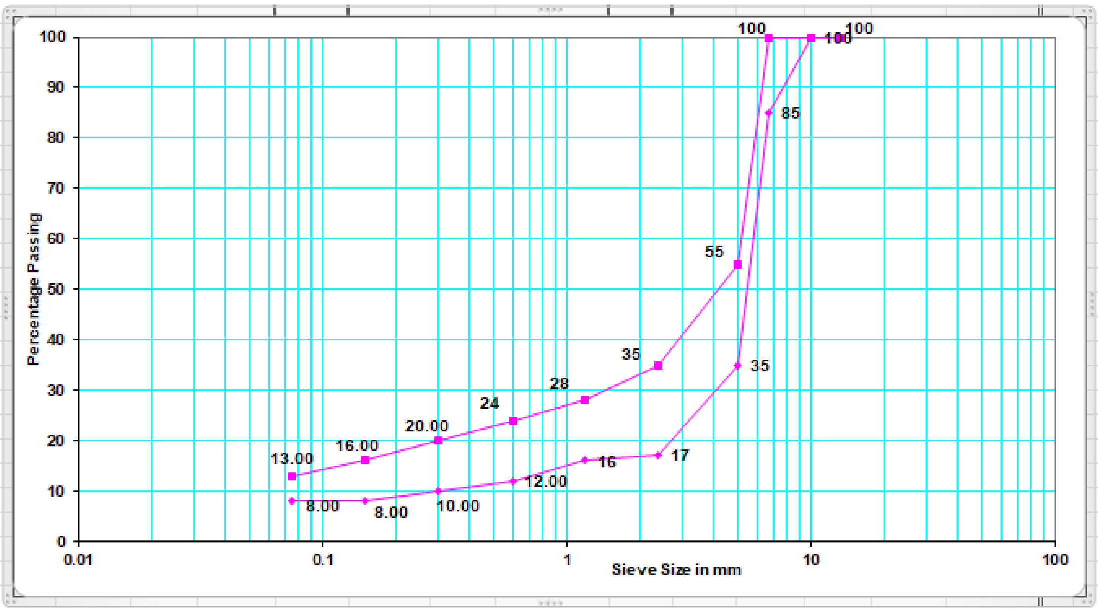


Figure 6.3:SMA 7N Graddation

The aggregates sourced from the asphalt plants come separately as hot bin samples. Aggregates were collected from the hot bins in asphalt plants, where they were sieved and collected inside respective hot bins. The aggregates were re-sieved using the standard sieves (*Table 6.1*) in the laboratory. This was done using the sieves as in the specification.

The aggregate blend was formulated from the retained aggregates on each of the sieves after completing the sieving. According to (*Table 6.2)*, the average passing

Figure 6.4:Classified aggregate

percentages were calculated for each sieve size. The mix was reverse-engineered using the calculated retaining percentages. The retaining percentages were calculated using the passing percentages given by the specification for each aggregate fraction. The calculated weight of each fraction used to create the mix (*Figure 6.5*) is shown in the *Table 6.2*

Table 6.2:Passing and retaining a percentage of aggregate

Sieve(mm)	Upper Limit%	Lower Limit%	Average Passing%	Retaining%	Retaining weight (g)
12.5	100	100	100	0	0
10	90	100	95	5	62.5
6.3	43	64	53.5	41.5	518.75
5	30	50	40	13.5	168.75
2.36	21	31	26	14	175
1.18	16	25	20.5	5.5	68.75
0.6	14	22	18	2.5	31.25
0.3	12	19	15.5	2.5	31.25
0.15	9	15	12	3.5	43.75
0.075	8	12	10	2	25
Pan	-	-	-	10	125

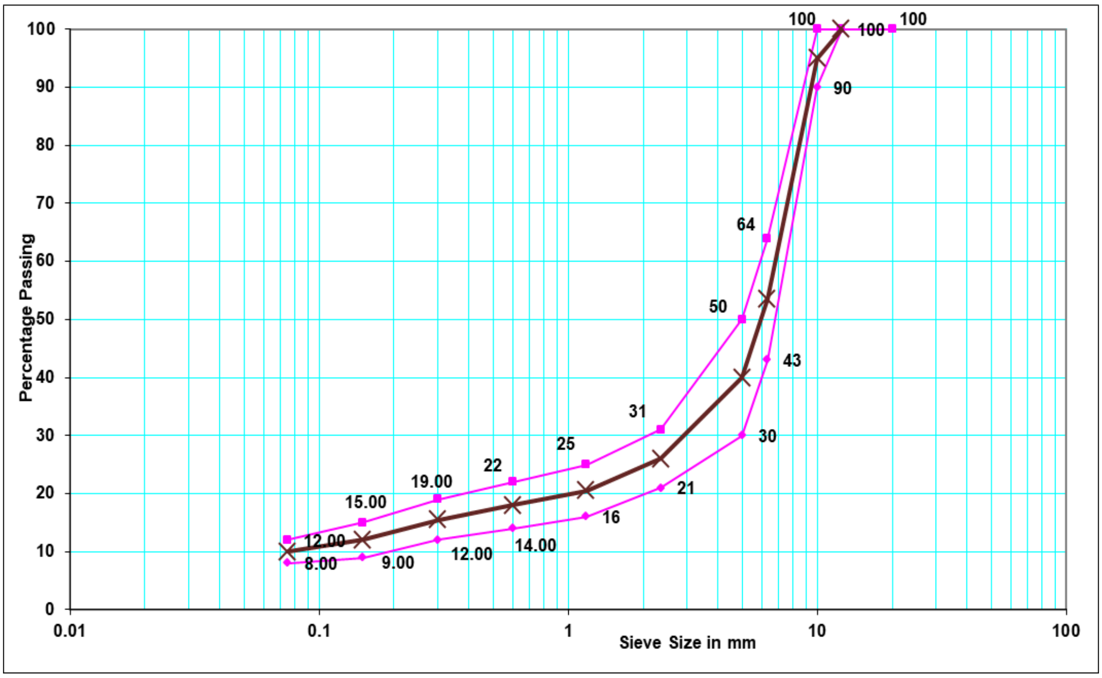


Figure 6.5:The average passing percentage

Figure 6.6:Mixed Aggregate

Figure 6.7:Mixing with bitumen

Trial mixes were prepared using varying bitumen contents from 5%-7% by weight and Marshalls were casted according to the specification by applying 50 blows per side. The aggregate blend was formulated according to the blended percentages given from *Table 6.2*

The Marshalls were then de-molded and tested to determine their Marshall properties such as the flow, air voids content, and stability. The variation of properties with the bitumen content was recorded after testing,

Figure 6.8:Compaction of the Marshalls

6.2 Incorporation of fibers

After analyzing the results, since the specification requires the addition of fiber to stabilize the mix, glass fibers where available commercial was added to the mix. Then to optimize the amount of fiber in the mix in order to achieve the most desirable properties. The amount of fiber added to the mix and length of the added fibers was changed, and Marshalls were casted using mixes with different bitumen and fiber contents. Then the Marshalls were tested for their volumetric, strength and resistance to deformation. The obtained results of different parameters were compared. The literature suggests that when a fiber is added, the parameters such as the length of the fibers affect the mix properties considerably. Therefore, the optimum length of fibers, which is suitable for the application, also needed to be found.

Two fiber lengths were tested to determine the optimum length, which provides the best Marshall properties. The Marshalls were casted with 6.5% bitumen and using fibers sized to 5mm and 10mm long sections and the diameter of the fibers remained the same(15µm). The Marshall parameters were tested afterward. From analyzing the trends of the test results, the suitable optimum fiber content is determined.

Figure 6.9: The glass fibers which were cut and prepared for mixing

6.3 Indirect tensile strength

Figure 6.10:Indirect tensile test

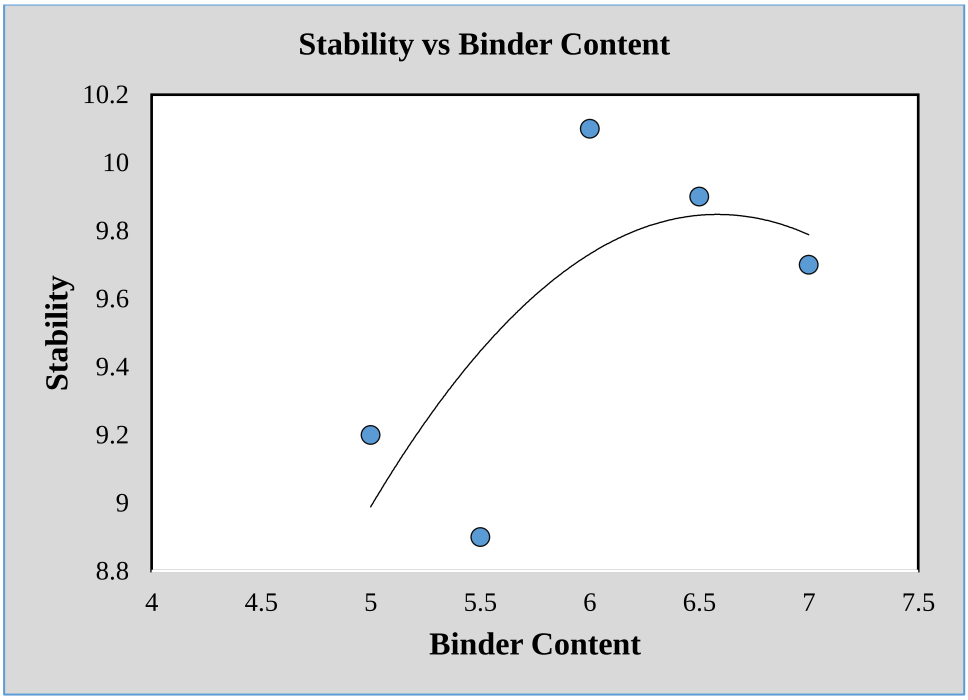
The indirect tensile strength is a parameter that provides an overall idea about the structural adequacy of the mix. This test is also used to research the structural contribution of incorporated fibers into the asphalt concrete. The hypothesis that the structural parameters could have a correlation with the fiber content was tested. The length of the fibers used can also affect the structural parameters, according to the literature. Therefore, the behaviors of both parameters were checked, the fiber length and the fiber content. A control sample with 6.5% bitumen was casted, and then 5mm length fibers were mixed to the aggregate bitumen mix, and then the Marshalls were casted. After the glass fibers which sectioned into 10mm long sections, and they were mixed with aggregate and bitumen, and Marshalls were casted the same way. Then the Marshalls were tested for their indirect tensile strength parameters.

7 Results

Initial testing results obtained from testing the Marshalls with different bitumen contents are shown in the *Table 7.1*. The graphs following the table show the variation graphically.

Table 7.1: Marshall Mix design for SMA mixtures

Binder Content %	Stability(kN)	Flow	Air Voids %	VMA
5	9.2	10.2	5.7	16.5
5.5	8.9	10	4.9	16.8
6	10.1	10.6	3.8	16.9
6.5	9.9	10.2	2.8	17.2
7	9.7	10.8	2.1	17.7



The Stability vs Binder content Variation is shown in *Figure 7.1*.

It is observed that with the bitumen content, the stability comes to a maximum at 6% and then reduces with increasing bitumen contents. According to the specified limits from the (Standard Documents, 2018)

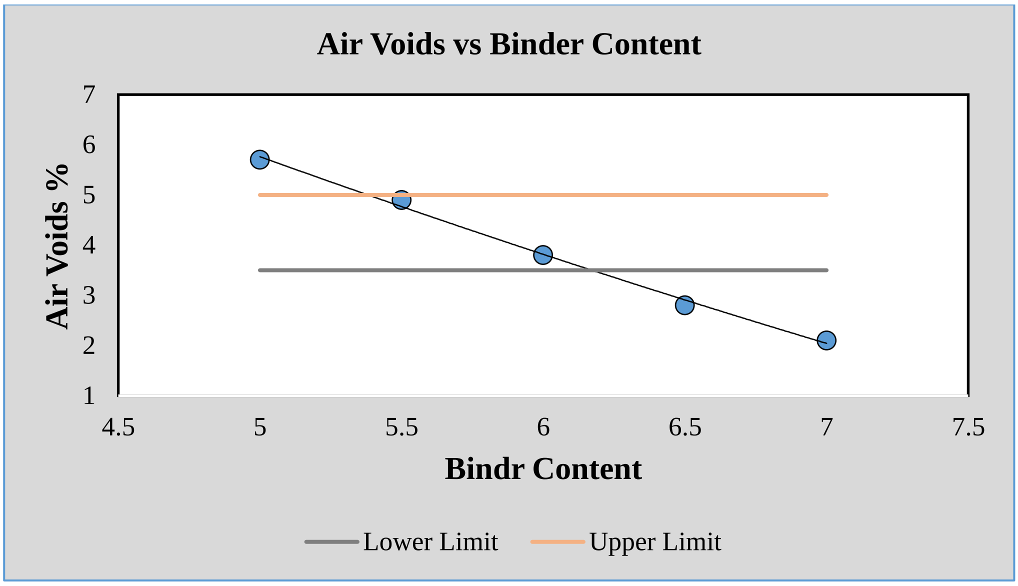


Figure 7.2:Air Voids Content vs Binder Content

Air voids content is one of the key parameters which affect the durability and performance of the mix. Air voids content should stay within 3.5-5% in order for the mix to be suitable for paving. The air voids present in the mix are responsible for the degree of aggregate-on-aggregate contact and interlocking properties of the mix, and it can also affect aggregate compaction parameters. The air voids are formed and reside in the voids between the coarse aggregate skeleton, including the asphalt binder, fine aggregates.

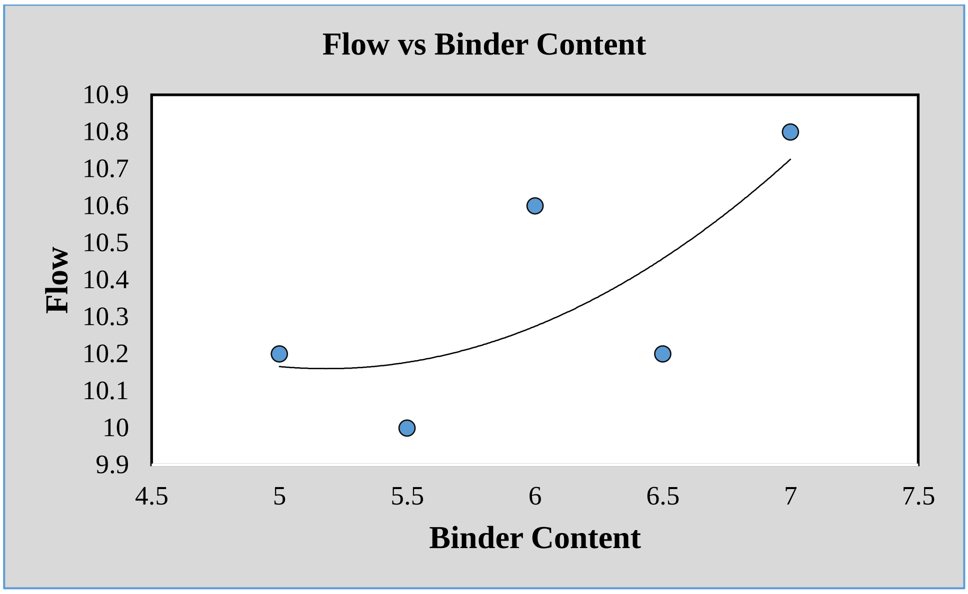


Figure 7.3:Flow vs Binder Content Variation

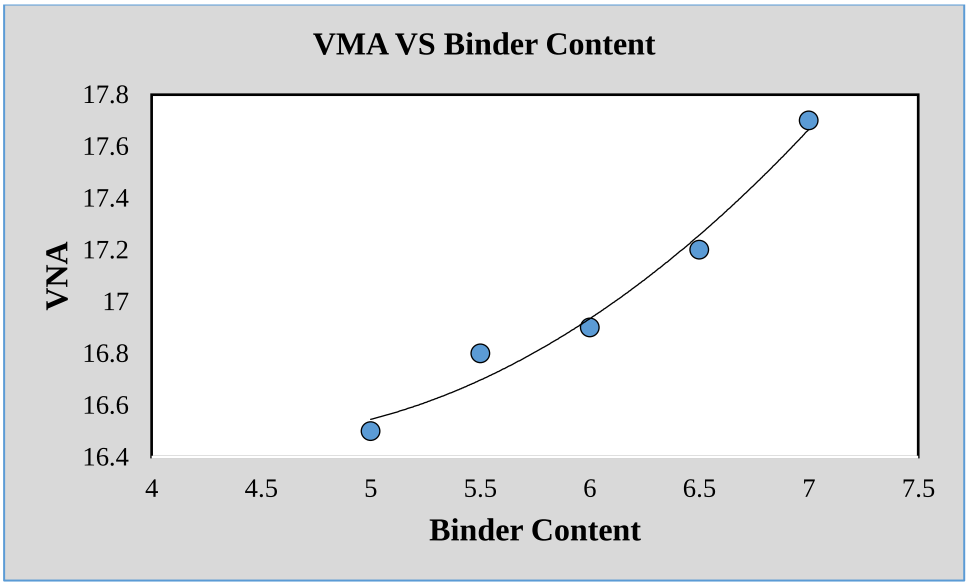


Figure 7.4:Vma vs Binnder Content

Voids in mineral Aggregates (VMA) is the term used to identify the air-void space, which exists only between the aggregate particles in a compacted asphalt concrete mix without a binder or any other additive. VMA also can be interpreted as the parameter that provides an indication about the available room for asphalt and the air voids, which accounts for the air voids content which remains unfilled. When the

VMA is higher, the room available to accommodate the coated binder becomes higher, facilitating high film thickness. It is established that high film thickness results in a more durable mix. In SMA the goal of using high bitumen content is to obtain a robust pavement. Therefore, a minimum specific requirement is established in every specification to avoid compromising pavement durability due to deficiencies in film thickness. If the aggregate mix density is higher than a certain level, the VMA values reduce beyond the minimum values and result in a dry mix with low durability. in order to achieve an optimum mix that is cost-effective and durable, and the VMA parameter should be taken in to care.
(Colarado Asphalt Pavement Association)

Table 7.2:The specification limits

Mix Size (mm)	**Stability (kN) Minimum**	**Air Voids (%)**		**Voids in Mineral Aggregates Minimum**
		Minimum	**Maximum**	
SMA10N	5.5	3.5	5.0	18
SMA10H	5.5	4.8	5.2	18
SMA7N SMA7H	5.5	2.5	5.0	19

The specification limits in *Table 7.2* are used as the main criteria for eliminating unsuitable mixes and achieving a desirable mix.

7.1 With Fiber

The Marshall properties when the glass fibers were incorporated into the mix is shown below. The length of the fibers were not taken into account as a parameter here and only the fiber content is considered. The mixes were created using 6% bitumen content to find the behavior of mixes when fiber is incorporated.

Table 7.3: Marshall mix design for SMA mixture with fiber

Fiber Content %	Stability(kN)	Flow	Air Viods %	Vma
0	9.5	9.8	3.3	17
1	8.8	10	3.6	17.4
1.5	8.2	15.2	5.3	17.9
2	6.7	16.2	5.6	18
2.5	5.9	17.6	8.4	18.1

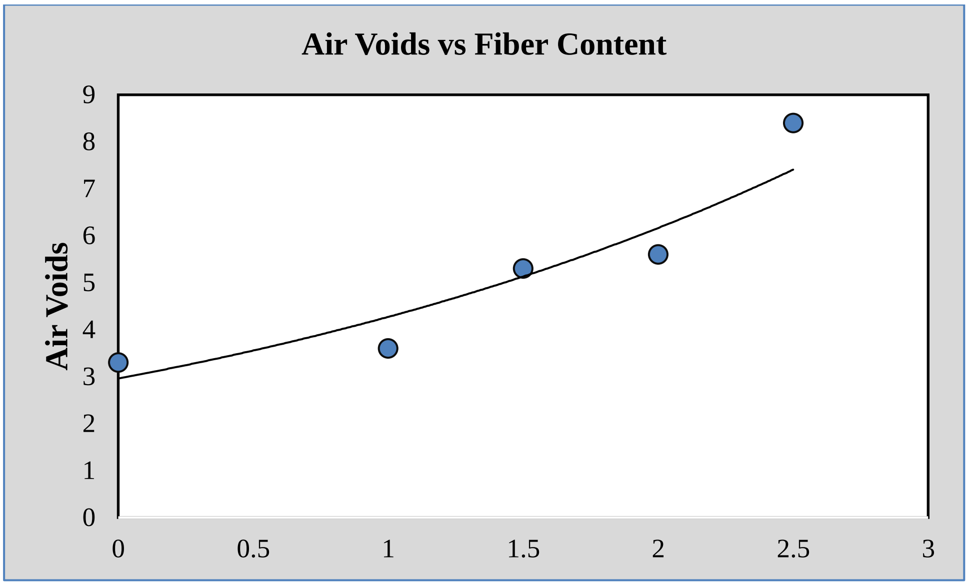


Figure 7.5:Air Voids vs Fiber Content

When the mixed fiber content increases, it is observed that air voids content also increases with the addition of fiber. When the amount exceeds a certain level, the fiber inhibits the compaction of the mix and aggregate on aggregate contact of SMA is compromised. Therefore, the structural properties may suffer though the volumetric properties are satisfied with the addition of extra fibers. The flow value has increased with the increasing fiber content

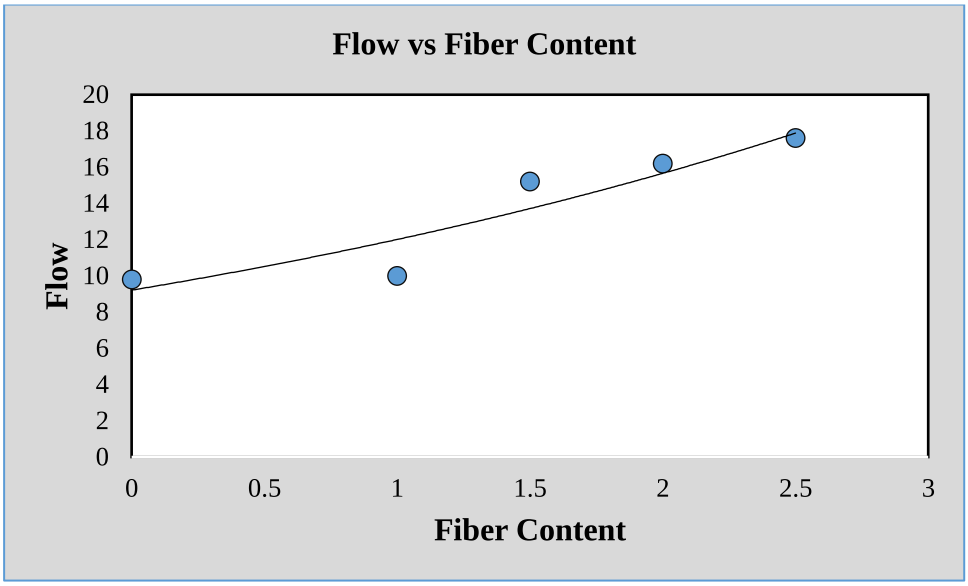


Figure 7.6:Flow vs Fiber Content

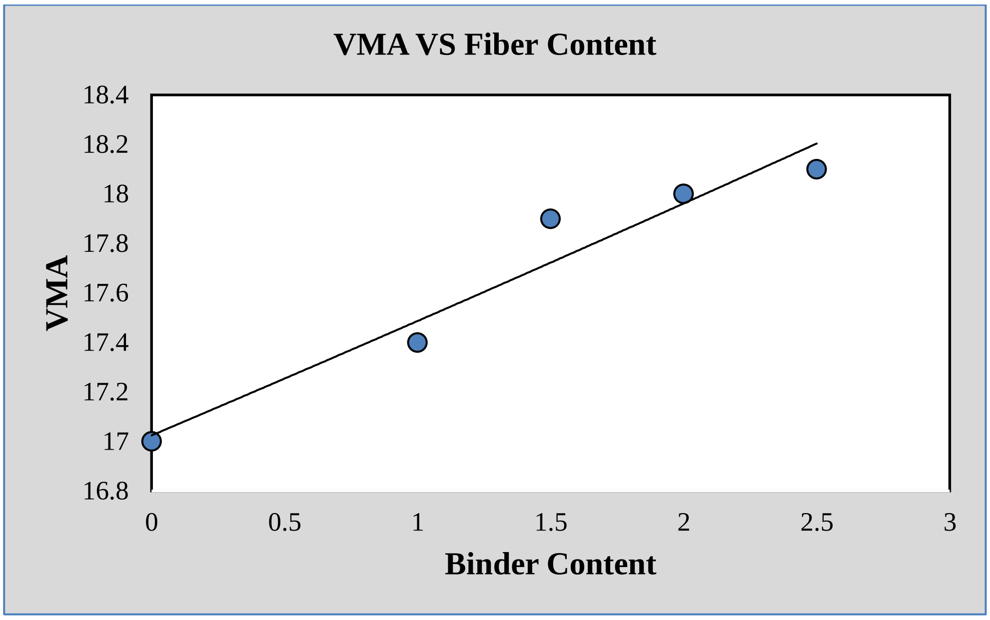


Figure 7.7:Vma vs Fiber Content

The addition of fibers increases the VMA. from the Marshalls casted with added fiber. It is evident that fibers can be used to raise the VMA values. When SMA is used, the VMA value is essential to maintain a sufficient film thickness.

The literature suggests that the length of fibers governs fiber-reinforced composites' strength properties. Therefore, to find out the mixes relationship with the fiber length, the Marshall tests were carried out, altering the fiber contents for two main fiber length classes. Fibers that were 5mm in length and 10mm in length were mixed with aggregate and binder. The Marshall parameters were obtained by conducting Marshall tests.

Marshalls were also casted with varying fiber contents as well as their lengths. The Marshalls were tested separately for their Marshall properties, namely stability air voids(VA) and VMA. The results obtained are shown from *Table 7.4* for 5mm fiber incorporated Marshalls and from *Table 7.5* for 10mm fiber incorporated Marshalls

Table 7.4:Marshall properties of 5mm fiber mixes

5mm Fiber Content(%)	Stability(kN)	VA(%)	Vma(%)
0	9.9	2.9	17
1	8.8	3.0	17.2
1.5	8.2	3.8	17.6
2	6.7	5.0	19.8
2.5	5.9	6.5	22.8

Table 7.5: Marshall properties of 10mm fiber mixes

10mm Fiber Content(%)	Stability(kN)	VA(%)	Vma(%)
0	9.9	2.9	17
1	7.4	6.0	17.5
1.5	6.9	6.6	18.1
2	5.7	7.3	20
2.5	5.1	8.5	23.2

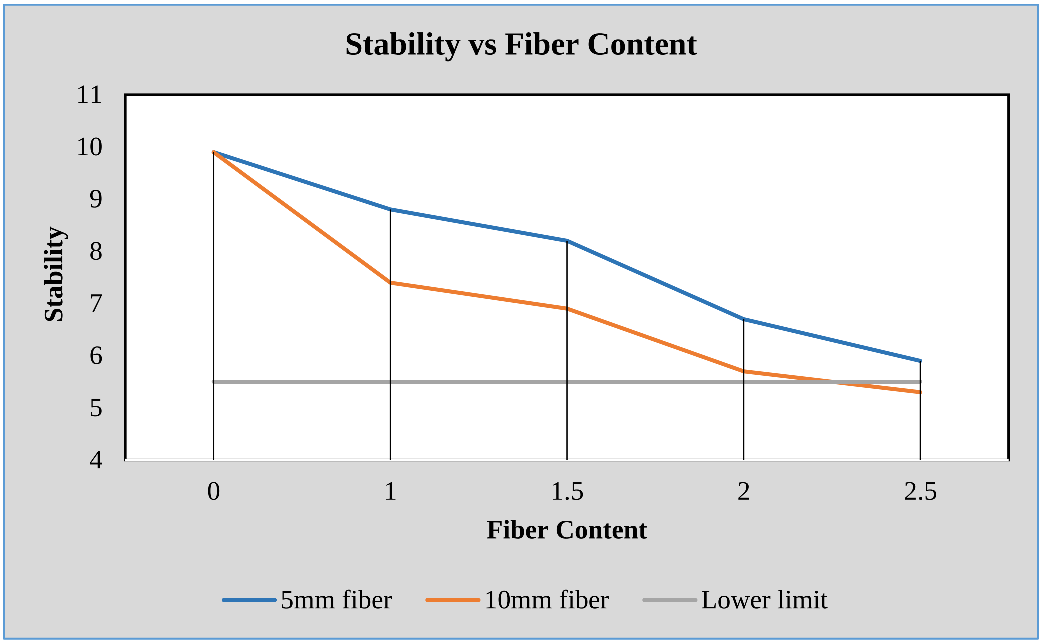


Figure 7.8:Stability vs Fiber Content

The samples casted with using both 5mm and 10mm fibers showed a reducing trend for the stability when fiber content was increased, but 5mm fibers, according to the graph, have maintained the stability parameter within the allowed range.

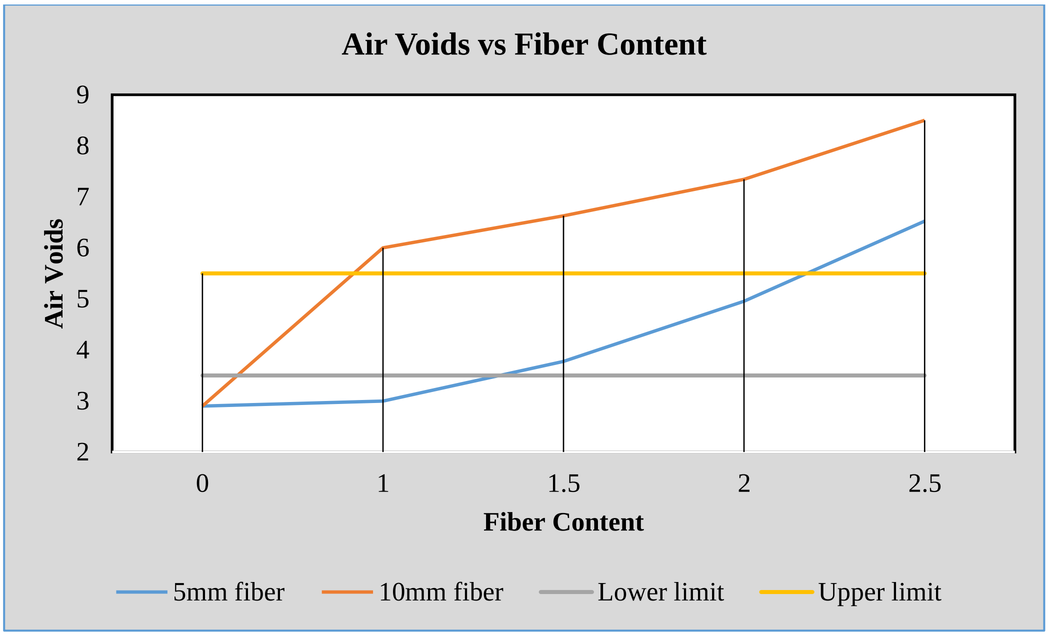


Figure 7.9:Air Voids Content vs Fiber content

The air voids content is a crucial property when it comes to asphalt concrete properties. The Marshalls with the 5mm fibers maintained the air voids content in the desired specification levels. When 10mm fibers were used, they inhibit the compaction by interfering with aggregate locking, thus increasing the voids exponentially

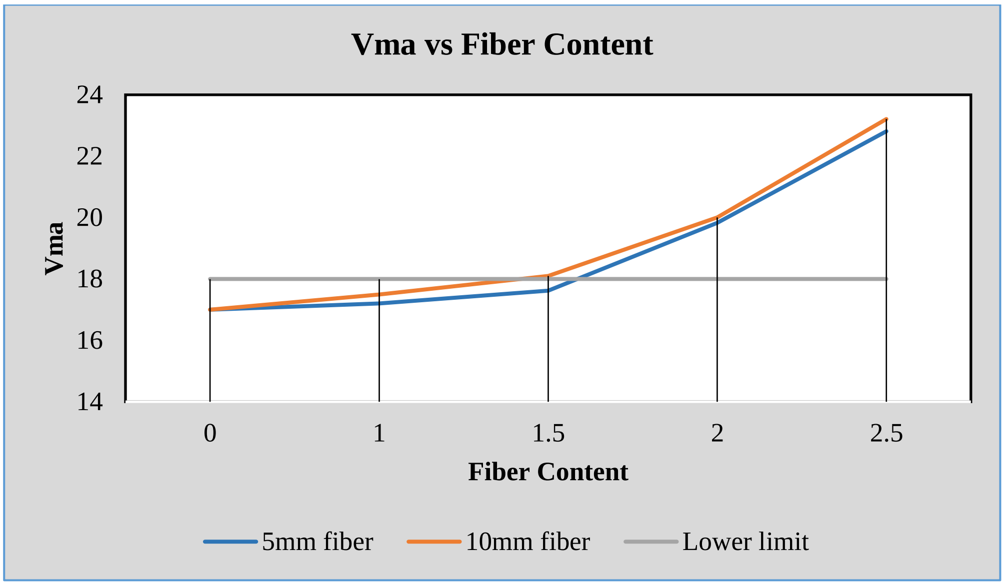


Figure 7.10:Vma vs Fiber content

The fiber addition tends to increase the VMA for the Marshalls with both length classes (5mm, 10mm). The Marshalls with 5mm long fibers show lower increment compared to the 10mm fiber included Marshalls. It is evident that fibers can be used to get high VMA values. In return, increased VMA provide space to include higher bitumen contents, thus increasing the film thickness of coated aggregates effectively

The indirect tensile strength variation was tested in order to observe the effect of the addition of fiber to the mix on the mix's tensile parameters. The results obtained from the tests are shown by *Table 7.6*. The indirect tensile strength provides indications about the structural performance of the

Table 7.6:Indirect tensile strength of fiber mixed Marshalls

Fiber content %	Indirect Tensile strength (MPA)
0	0.404
1	0.451
1.5	0.435
2	0.428

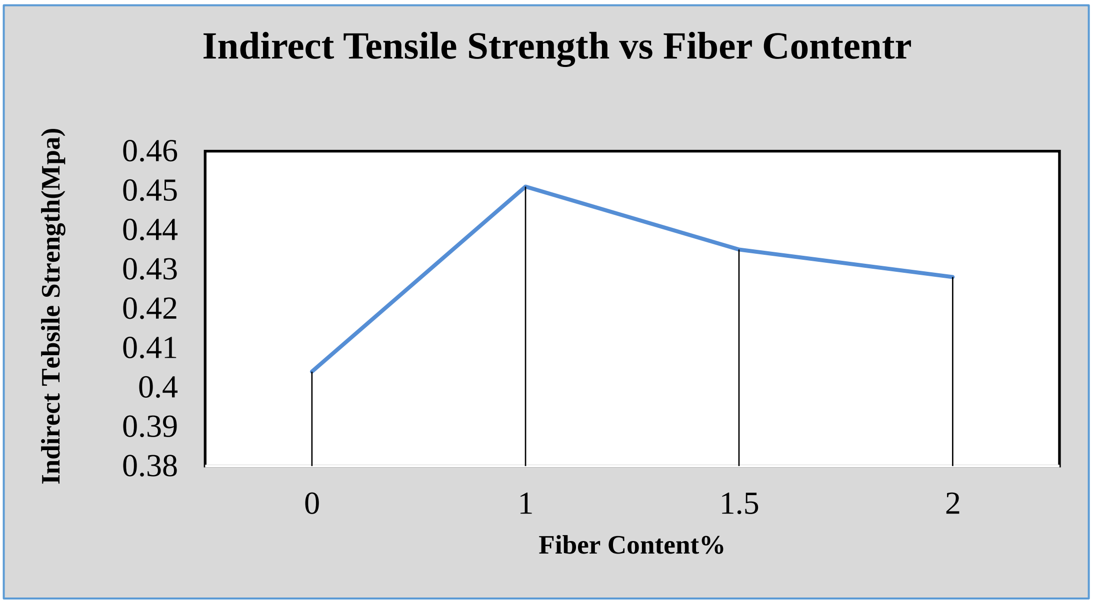


Figure 7.11:indirecrt tensile strength variation with fiber content

8 Discussion

Since there is a significant interest in upgrading the rural low volume roads in Sri Lanka at present, this approach aims to find out the suitability of thin asphalt layers (25mm-30mm), which are cost-effective and material saving compared to the commonly used 20mm mix. In this research,the mix properties of the 10mm stone matrix asphalt design extracted from Vicroads (Standard Documents, 2018) specifications were tested for local applicability using locally available aggregate and bitumen.

The first approach was to determine the optimum bitumen contents where the mixes satisfy the specified criteria for VMA,VA and Marshall Stability.Marshalls were casted with varying bitumen content from 5%-7% and tested. The mixes having 6% and 6.5% bitumen with no added fiber displayed the most promising results and there fore they were taken for further tesing with added fibers.The mashalls having 6% bitumen contet failed to achieve the required VMA values with added fiber and there for marshalls with 6.5% bitumen content were tested using fibers and it a successful mix was achieved.

The Stone mastic asphalt mix is a bitumen-rich mix by nature, and to stabilize the mix, it requires the addition of fiber to the mix. The function of the fiber is to absorb the additional bitumen and stabilize the mix while preventing any possible drain down. The fiber additive that the specifications recommend is cellulose fibers. But for this research, waste glass fiber was incorporated as the fiber additive to the mix. The *Table 8.1* provides the pros and cons of both fiber types according to the external refernces.

Table 8.1:Cellulose fiber vs Glass fiber

Fiber Type	**Advantages**	**Disadvantages**
Cellulose	• Stabilizes binder in open and gap graded SMA mixes • Absorbs binder allowing high bitumen content mixes	• Not readily available in Sri Lanka • High binder absorption • Does not perform under tension • Cost is high • No improvement to the structural value
Glass Fiber	• High tensile strength • Low elongation • High Elastic Recovery • High Softening point • Availability as waste • Low cost • Easy preparation • Improves the tensile properties of the mix	• Brittle can crack • May break during mixing and compaction • Hazardous material

Then trials were carried out to find the effect of the fiber addition for the mixes. Fiber contents were varied, keeping the aggregate structure and binder contents constant and the Marshall parameters were measured. The observed variations displayed that adding fiber causes the Marshall properties to change drastically. The air voids content and VMA values variation were very evident with the addition of more fibers. At the same time, they were retaining the stability values within the specification limits.

The next parameter was the effect of fiber length. The fiber length is a crucial parameter when it comes to the fiber-reinforced composite properties. Therefore, glass fibers sectioned into 10mm and 5mm were added respectively to the mix, and the behavior was analyzed mixes with the 5mm long fibers incorporated showed superior properties than the mixes with 10mm fiber sections.

Then, to check the structural parameter behavior with fiber addition, the indirect tensile strength test was carried out. The results showed an increase in indirect tensile strength when fibers are added.

9 Conclusion

Thin SMA wearing surface layers could be applied to roads where traffic movements are limited. The 10mm aggregate mix gives the ability to pave a 25mm-35mm successfully. With quality aggregates used for the construction, and where the traffic movements falls under the low volume category since this mix satisefies the specification requirements and can be applied on sites.

The SMA mixes require fibers to stable the mix since they retain high bitumen content. The glass fibers are proven to be a versatile addition that facilitates bitumen retention and provide the required tensile reinforcement to thin asphalt pavement.

A successful mix that complies with the standard can be achieved with a mix with 6.5% bitumen to weight and the addition of 1.6% to 2% glass fiber to the mix.

The road base construction is much as important as the surfacing when it comes to thin asphalt pavement. Therefore, extra care and quality control measures need to be taken into account when constructing a thin asphalt pavement base.

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