Bitumen Retention of Modified Open Graded Asphalt Using Sisal Fibre and Waste Plastics

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Abstract- To investigate the behavior of sisal fibre and waste plastic modified asphalt concrete mixes, a study was done to determine the feasibility of modifying the behaviour of open graded asphalt (OGA) concrete mix through the use of sisal fiber and waste plastics. The main objective of this research was to analyze and study how a combination of sisal fibre and waste plastics can be used to reduce bitumen drain down and effectively utilize waste plastics in construction of flexible pavement to improve on strength.

A thorough study was done on the methodology of using locally-available waste plastics and sisal fibre as stabilizer and present the various tests performed on aggregates, bitumen and asphalt concrete. Aggregates sizes 12/6 mm and waste plastics size 2-3mm were heated and mixed until plastics melted and coated aggregates. Thereafter, sodium hydroxide (NaOH) treated sisal fibre, shred into 5 mm long threads was mixed with hot bitumen. The mixture of bitumen and sisal was added to coated hot aggregates at specified temperature. The resultant mix was analyzed for bitumen retention properties to assess sisal-plastic ability to reduce bitumen loss.

Using Marshall procedure, optimum sisal content (OSC) was 0.3% and optimum plastic content (OPC) was 5% for modified asphalt concrete mixes prepared using optimum binder content (OBC) of 5.5%. It was established that bitumen drain down was 0% when a mixture at optimum contents of sisal fibre and waste plastics are used. The non-modified samples had bitumen drain down of 6.5%. this shows that the sisal-plastic additives have high bitumen retention due to the absorptive nature of sisal fibre.

Use of sisal fibre and waste plastics will strengthen the road pavements as well as help to improve the environment.

Index Terms- Waste plastics, sisal fibre, open graded asphalt (OGA), sisal-plastic modified open graded asphalt (SPMOGA), Marshall test, stability, flow, voids, drain down

I. INTRODUCTION

Drain down is considered to be that portion of the mixture (fines and bitumen) that separates itself from the sample as a whole and flows downward through the mixture (NAPA, 1999). Drain down test is more significant for open graded asphalt (OGA) mixtures than for conventional dense-graded mixtures because the former tends to lose bitumen during transportation and laying of asphalt concrete. It can be used to determine whether the amount of drain down measured for a given bituminous mixture is within the specified acceptable levels. This test is primarily used for mixtures with high coarse aggregate content where the internal voids of the uncompacted mix are larger, resulting in more drain down such as stone matrix asphalt and open-graded friction course (Huang et al., 2007).

Disadvantages associated with OGA mixtures are drainage and bleeding at high temperatures. However, temperatures cannot be made low during Storage and placement due to difficulty experienced in obtaining the required compaction (Bindu and Beena, 2009). Stabilizing additives can therefore, be added to stiffen the mixture thereby improve the bitumen retention at high temperatures. This ensures that we retain higher bitumen contents for increased strength and durability (FHA, 1992).

OGA concrete mix has higher bitumen binder content of between 5-7% by weight of mix compared with dense graded asphalt. Hence, high bitumen content and filler results into bitumen drain down. This makes the aggregate lose the binder that binds the aggregates together in the mix (Huang et al., 2007). The loss of bitumen and uneven distribution of bitumen as a result of drain down can result into top sections of mixture have less bitumen content. this can also result into mix with less of permeability in sections with higher concentrations of binder content (Bindu and Beena, 2014; Mallick et al.,2000).

II. MATERIALS AND METHODS

2.1 Materials

Materials used in this study are 80/100 penetration grade bitumen, graded aggregate of nominal size 12/6 mm, treated sisal fibre of diameter 0.1 to 0.4 mm and length of 5mm, shredded waste plastics of 2-3 mm. Marshal Test procedure was used in the investigation for study of behaviour of sisal-plastic modified open graded asphalt mix.

2.1.1 Aggregates

The coarse aggregate used was sizes 12/6mm. properties that were determined by standard tests are as given in Table 1.

Table 1: properties of the aggregates

S/No.	Test	Permissible Value	Test Value	Standard
1	Sieve analysis	See Fig. 1	See Fig. 1	ASTM C136/C136M – 14
2	Impact value (%)	<30%	27%	BS EN 1097-2:2010
3	Crushing value (%)	<30%	26%	BS EN 1097-2:2010
4	Abrasion value (%)	<30%	28%	BS EN 1097-8:2009
5	Specific Gravity	2.72	2.5-3	BS EN 1097-6:2013

The grading was done in accordance to ASTM C136/C136M – 14. The aggregate sizes were found to be within the grading range as shown in Figure 1. From the results, OGA is expected to have high cohesion due to grain-to-grain contact, high void content due to less fines and high permeability as a result of high coarse aggregates of 70%. The results obtained for impact value, crushing value and abrasion values indicates that the aggregates are able to bear the require loads without undergoing further disintegration. Breakdown of aggregates produces further fines, weakens the road pavements, thus resulting into cracks and pothole development. The specific gravity results found indicated that aggregates are less porous. Bitumen absorption would low and therefore much of it will go into binding the aggregate particles together. These characteristics of OGA make it best suited for road surface layer which provide required friction and noise reduction.

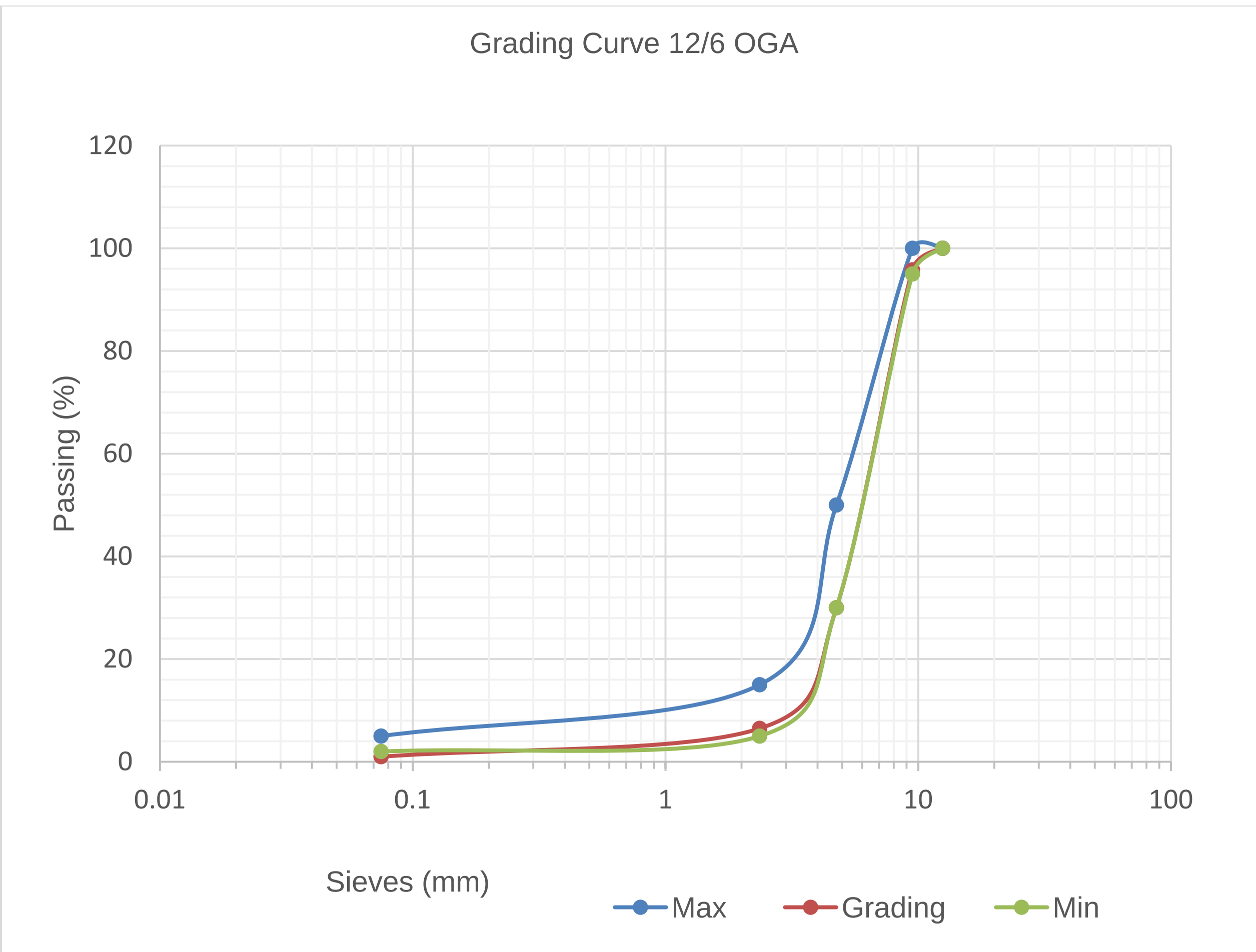

Figure 1: Grading curve for 12/6 mm aggregate for OGA mix.

Figure 1 shows the aggregate size 12/6 mm, whose composition ratio of course aggregates and fines are 70:30. The grading curve lies between the limits for aggregates to be used in preparation of OGA mix. The coarse aggregates are more compared to fines. This results into a strong asphalt mix with due to stone to stone grain contact.

2.1.2 Bitumen

In this research 80/100 penetration grade bitumen was used as binder for preparation of mixes. The resultant properties of the bitumen that were determined by standard tests are given in Table 2.

Table 2: Properties of bitumen

S/No.	Test	Permissible Value	Test Value	Standard
1	Penetration in mm at 25°C	89	80-100	BS EN 1426:2015, BS 2000-49:2015
2	Softening Point (°C)	47	42-50	BS EN 1427:2000, BS2000-58:2000
3	Ductility	105	75 min	ASTM D113-17
4	Specific Gravity	1.02	1.01-1.05	ASTM D70-97

From table 2, it is observed that Bitumen class 800/100 properties are within the permissible values. Penetration is a measure the consistency of bitumen. This shows that this bitumen grade can be used in cold climate and hot climate areas. Softening point is the tendency of the material to flow at increased temperature. The result indicate that the bitumen can be properly mixed with aggregates at when heated. Ductility results indicates that this grade of bitumen can be used to prepare asphalt that can withstand elongation within the ASTM D113-17standard requirements without breakage. Hence compaction can be done to required level and pavement can withstand the traffic load without cracking.

From the bitumen properties, it is seen that it is suitable to be used as a binder in the manufacture of asphalt concrete.

2.1.3 Waste Plastics

A mixture of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) were shred to size 2-3 mm. Properties determined by standard tests are given in Table 3.

Table 3: Properties of waste plastics.

S/No.	Test	Permissible Value	Test Value	Standard
1	Specific gravity	1.3-1.4	1.4	ASTM D1505-18
2	Softening point	No gas release	No gas release at 100°-120°C	
3	Binding properties	>10 N/mm^2	14 N/mm^2	

From table 3, the specific gravity of the waste plastics indicates that the material is relatively dense and within the standard ASTM D1505-18. this shows that the introduction of this material in asphalt concrete can strengthen it by binding the aggregate grains together. The softening point indicates that the waste plastics can be used to increase the softening point of asphalt concrete for use in hot climatic conditions. The non-release of gases at high temperature shows that the materials can be heated up and mixed with aggregates without release of gases that impact negatively on the environment. The binding properties of the waste plastics is an indicator that it can be used to bind aggregate particles together to produce a mixture with high stability. This wound product a strong pavement that can resist cracking and rutting

2.1.4 Sisal Fibre

Sisal fibre was tested for various properties as indicated in Table 4.

Table 4: Properties of sisal fibre.

Properties of Sisal Fibre Tested	Values	Permissible Range
Diameter (mm)	0.11	0.1-0.4
Density (g/cm^3)	1.33	0.67-1.5
Natural moisture content (%)	11.5	11.44-15.85
Tensile strength (MPa)	180.6	108.26-251.9
Water absorption (%)	98	85-135
Strain at failure (%)	23.6	13.7-41.0

From the results of various properties, it was found out that the parameters are within the permissible range indicated in Table 4. The results of diameter, strength and strain shows that sisal fibres can be used as stabilizers for open graded asphalt. They can hold aggregates particles and bitumen into a firm matrix mixture.

III. Laboratory Mix Design and Analysis

Marshall Stability test was conducted on non-modified OGA samples by applying 50 blows on each face. Bituminous mixes were prepared by mixing the graded aggregates with 80/100 penetration grade bitumen and required additives. 5.5% optimum bitumen content of control OGA mix was determined by Marshal methods. 5mm sisal fibre, treated with weak sodium hydroxide (NaOH) and shredded waste plastics, 2-3mm, were used as the modifiers. The fibre content in this research was varied between 0.1%, 0.2%, 0.3% and 0.4% by weight of mix and waste plastics content varied from 1%, 3%, 5% and 7% by weight of mix. The sisal fibre and waste plastics content that gave the optimum marshal mix parameters were used to prepare sisal-plastic modified open graded asphalt (SPMOGA) concrete samples. These SPMOGA samples were analyzed for drain down characteristics as discussed herein. Waste plastics were added in heated aggregate and mixed to obtain homogeneous mixture. Sisal fibre was then treated with sodium hydroxide solution prior to mixing with heated bitumen. The Plastic-coated aggregates are mixed with sisal fibre and bitumen. The mixing and testing temperatures were kept at 165°C and 150°C respectively.

3.1 Determination of Bitumen Content

Three samples of open graded asphalt (OGA) concrete were prepared for each bitumen content. The bitumen content was varied from 4.5% to 6% of total weight of sample. It was observed that Specific gravity increases with increase in percentage of bitumen up to 5.5% of bitumen content and then drops with increase in bitumen content. The corrected Marshall stability increased with increase in bitumen content up to 5.5% when the reduction was noticed as seen in Figure 2(b). Marshall flow values were found to range between 2.98-3.21 mm while percentage of void (V_v) in the total mix ranged between 6.40-4.05%. Figures 2(a), 2(b) and 2(c) show the variation of performance of the mix in varying bitumen content.

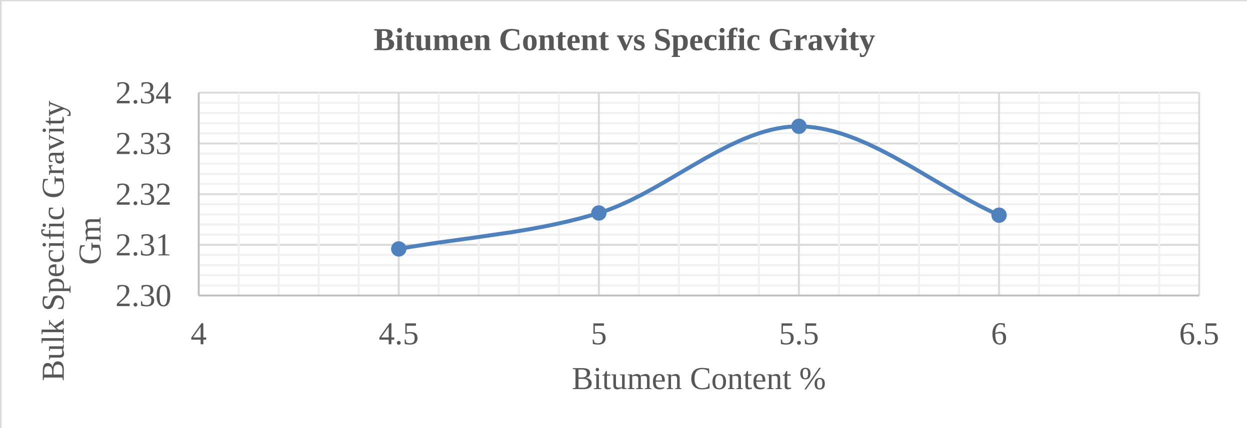

Figure 2(a): Bitumen content vs density of mix.

Figure 2(a) shows the variation in bulk specific gravity of the mix at various bitumen content. It was observed that the maximum specific gravity of 2.333 was achieved at 5.5% of bitumen content. Specific gravity is used to calculate the amount of asphalt absorbed in asphalt mixture, which is then used in determining the effective asphalt content. As more bitumen content is increase from 4.5% to 5.5%, there is increase in specific gravity. This is due to absorption of bitumen by aggregates, thus filling the pores and voids of the aggregates. However, beyond 5.5%, the specific gravity decreases due to excess bitumen content which increases the volume of the mix, with no significant change in mass.

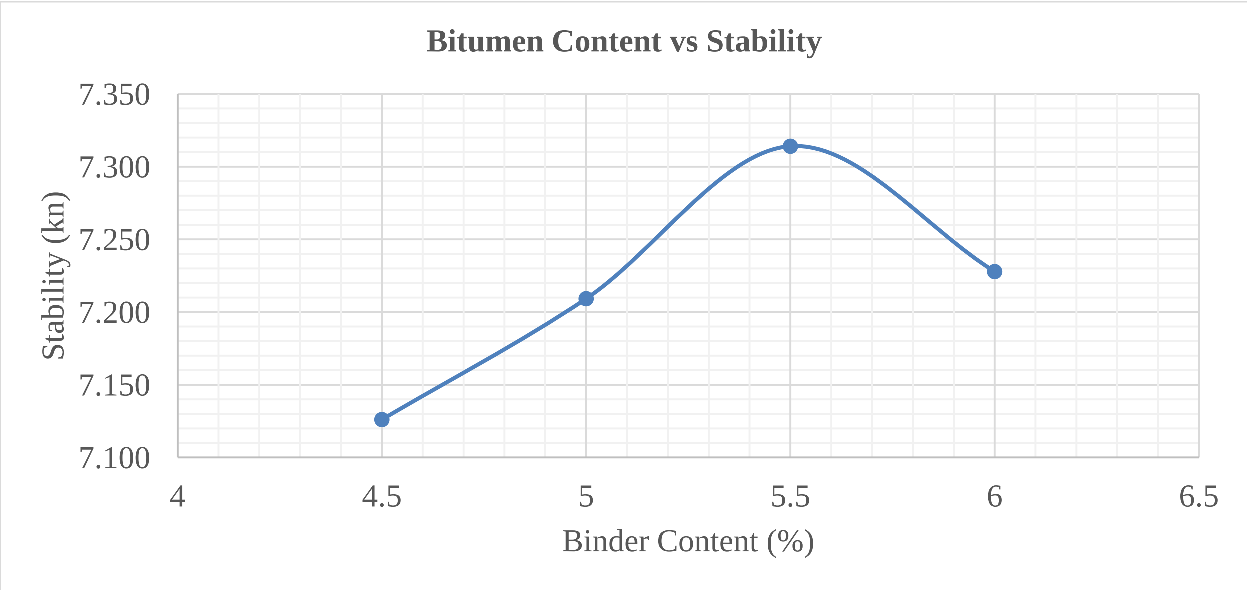

Figure 2(b): Bitumen content vs stability.

Figure 2(b) shows the variation in corrected stability of the mix at various bitumen content. It was observed that the maximum stability of 7.314 kN was achieved at 5.5% of bitumen content. it is observed that the stability of mix increases with bitumen content up to 5.5%. this is attributed to binding properties of bitumen. It binds aggregate particles together as its content is increased. However, beyond 5.5%, bitumen wetting of aggregates sets in. the dispersion of aggregates due to high bitumen content takes place, thus reducing aggregate to aggregate particle contact, thus affecting cohesion. Hence reduction in strength.

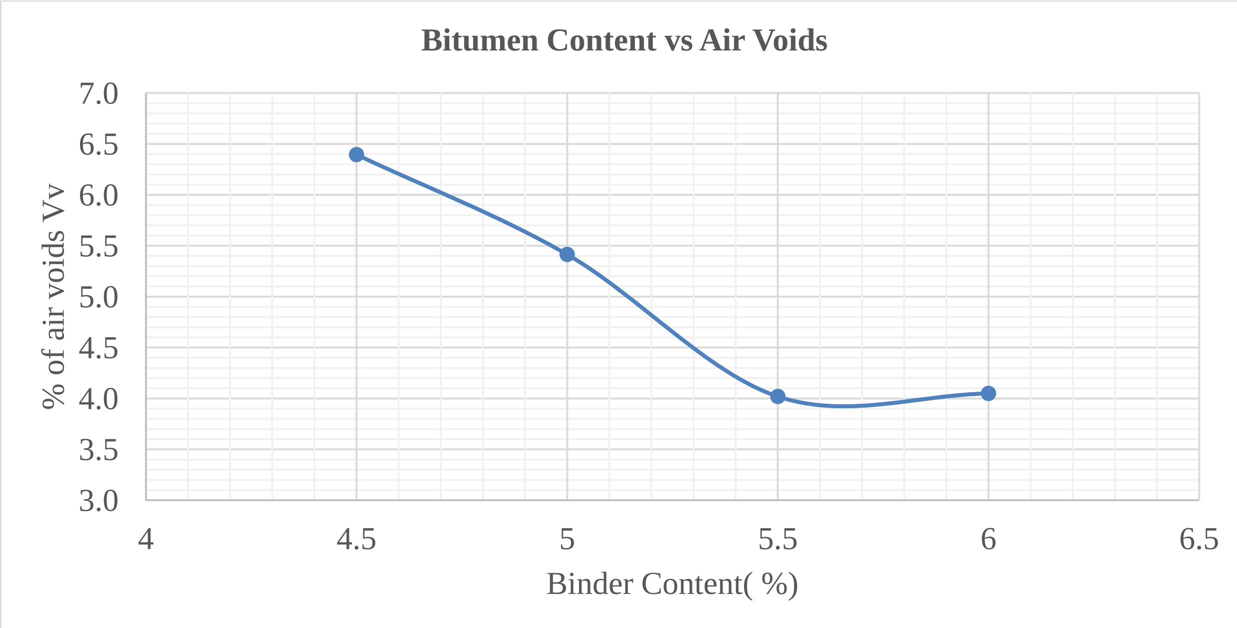

Figure 2(c): Bitumen content vs % Air voids

Figure 2(c) shows the variation in percentage air voids of the mix at various bitumen content. It was observed that the 4.02% air void was achieved at 5.5% of bitumen content. It was observed that air voids reduced with increase in bitumen content. this is associated with filling of air spaces and voids by bitumen content. Air voids is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. Air voids that are either too high or too low can cause a significant reduction in pavement life. air voids between 3 and 5% generally produce the best compromise of pavement strength, fatigue life, durability, raveling, rutting and moisture damage susceptibility.

Optimum bitumen content was calculated using Equation 3.1

$$B_0 = \frac{5.5+5.5+5.5}{3} = 5.5\% \quad \ldots\ldots 3.1$$

This OGA concrete mix without additives was considered as the control mix for the subsequent studies.

3.2 Drain Down Characteristics of Sisal-Plastic Modified OGA

This test is intended to simulate conditions that the mixture is likely to encounter as it is produced, stored, transported, and placed at high temperatures. The loose mixture was placed in a wire basket which was positioned on a pre-weighed dry paper plate. The entire apparatus was placed in the oven for one hour at 177°C. After one hour, the basket containing the sample was removed from the oven along with paper plate. The paper plate was weighed to determine the amount of occurred drain down. The drain down was calculated as the percentage of binder which drained out of the basket compared to the original weight of the sample. The average of three normal tests was reported as the drain down.

Results of drain down at various percentages of additive contents are given in Tables 5, 6 and Figure 3 and 4. From Tables 5 and 6, it can be observed that the additives provide higher stabilization to the mixture in comparison to the control mixture without additives. Drain down of the control mixture is 6.5% which is beyond the specified limits 0.3% as per AASHTO T305. It is seen that in the modified OGA mixtures, of drain down reduces with increase in modifier content and up to sisal fibre optimum value of 0.3 % and 5% waste plastic content. Effects of the inclusion of sisal fibre and waste plastics in OGA mixtures are prevent the bleeding phenomenon of the mixtures and bitumen drain down. From the results, it can be concluded that sisal fibre and waste plastics can be used as the OGA modifiers improve its bitumen retention properties.

Table 5: Drain down values for different percentages of sisal fibre

Sisal Fibre (%)	Drain Down (%)
0	6.489
0.1	2.340
0.2	0.136
0.3	0.008
0.4	0.000

Table 6: Drain down values for different percentages of waste plastics

Waste Plastics (%)	Drain Down (%)
0	6.489
1	3.610
3	1.426
5	0.804
7	0.330

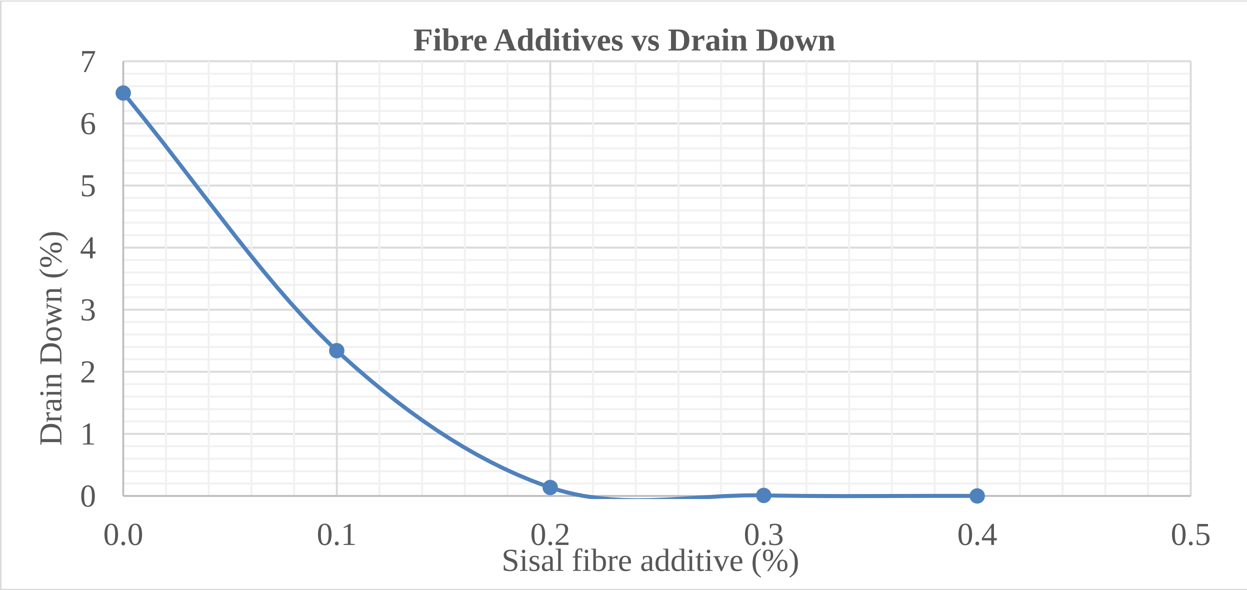

Figure 3: Variation of drain down with different percentages of SF.

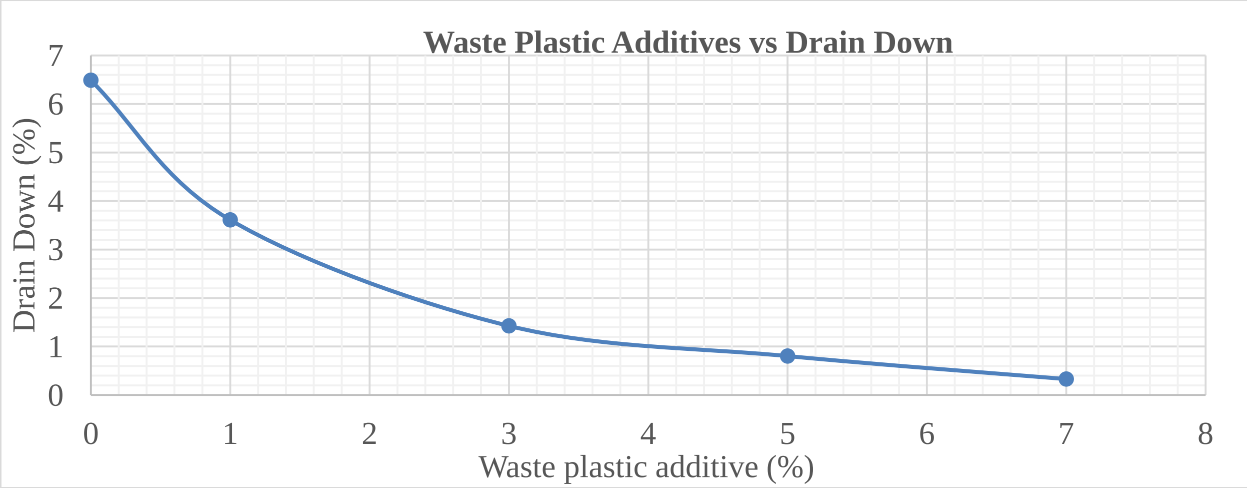

Figure 4: Variation of drain down with different percentages of waste plastics.

3.3. Bitumen retention of combination of Sisal fibre and waste plastic

Figure 5 shows the results of bitumen drain down when sisal fibre and waste plastics have been used together as OGA modifiers. The bitumen drain down for control mix was 6.5% while for that of 5% waste plastic modified samples was 0.8%. However, the drain down for samples modified with 0.3% sisal fibre alone and samples with sisal fibre together with waste plastics at optimum contents was 0%. It can therefore be concluded that the drain down for mix without modifiers was high as compared to samples with additives as shown in Figure 5.

Sisal fibre has strong stabilizing ability as compared to waste plastics. This is associated to the absorption ability of sisal fibres. Sisal fibres and waste plastics bind the aggregates to make a firm and stiff. This enhances bitumen retention and reduces bleeding. This makes the mix produce strong asphalt that can withstand traffic load without cracking or rutting.

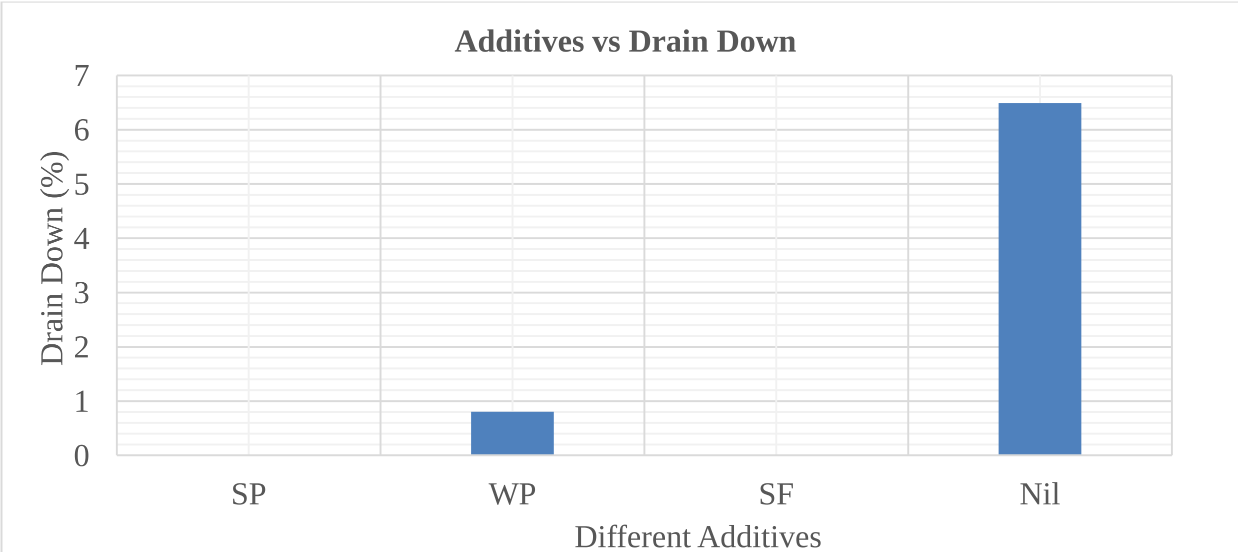

Figure 4: Drain down results for different additives

IV. Conclusion

This experimental work shows that sisal fibre and waste plastics can be used in the modification of open graded asphalt (OGA) to improve on bitumen retention. The drain down was found to be 0% for combination of sisal fibre and waste plastic modified samples as compared to 6.5% for control mix and 0.8% for waste plastic modified samples. The work of modifiers was to hold the aggregates and bitumen together in stiff matrix form. This increases bitumen retention at high temperatures during storage, transportation, placement and compaction of OGA mixtures.

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