Analysis of Bitumen Drain down Characteristics of Sisal-Plastic Modified Open Graded Asphalt

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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 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 2-3 mm size of waste plastics were heated and mixing done until plastics melted and coated aggregates. Thereafter, sodium hydroxide (NaOH) treated sisal fibre, shred into 5 mm long threads was mixed with hot bitumen and coated hot aggregates at specified temperature. The resultant mix was analyzed for bitumen retention properties to assess its suitability for road construction.

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 of Sisal-Plastic modified samples was 0% while non-modified samples had bitumen drain down of 6.5%.

The use of this innovative technology will strengthen the road construction industry as well as help to improve the environment. This would further their successful application as construction material in flexible pavement to improve road performance.

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. 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 (the internal voids of the uncompacted mix are larger, resulting in more drain down) such as stone matrix asphalt and porous asphalt (open-graded friction course) (Huang et al., 2007).

Potential problems with OGA mixtures are drainage and bleeding. Storage and placement temperatures cannot be lowered to control these problems due to the difficulty in obtaining the required compaction (Bindu and Beena, 2009). Therefore, stabilizing additives has been added to stiffen the mastic and thereby reducing the drainage of the mixture at high temperatures and to obtain even higher binder contents for increased durability (FHA, 1992).

OGA mixtures exhibited a very high bitumen binder film thickness (5-7% by weight of mix). This high binder content and the filler content (compared to that of dense-graded HMA) lead to higher susceptibility for the bitumen binder to drain off the aggregate skeleton (i.e., drain down) in mixtures (Huang et al., 2007). Irregular distribution of bitumen binder due to its drain down can lead to raveling of zones with low bitumen binder content and reduction of permeability in zones with accumulation of bitumen binder (Bindu and Beena, 2009; 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 normal weight aggregate with varying sizes of open graded (12-6 mm). Salient properties of the aggregates that were determined by standard tests are given in Table 1.

Table 1: Salient 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

It was found to be within the OGA % grading range as shown in Figure 1. From the results, it is expected to have Grain-to-grain contact, high void content and high permeability. These characteristics of OGA make it best suited for road surface layer, thus providing required friction and noise reduction on road surface.

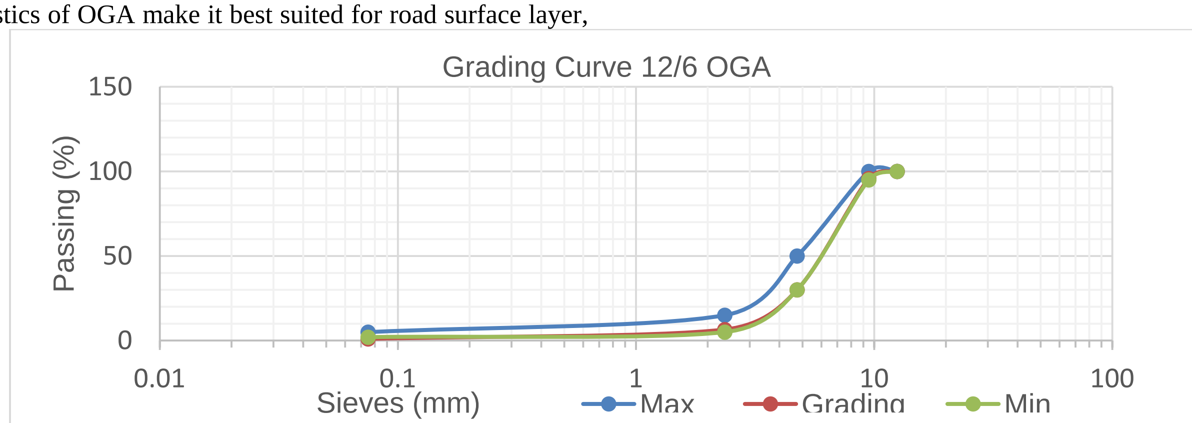

Figure 1: Grading curve for 12/6 mm aggregate for OGA mix.

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.

2.1.2 Bitumen

In this research 80/100 penetration grade bitumen was used as binder for preparation of mixes. Salient properties of the bitumen that were determined by standard tests are given in Table 1.

Table 1: Salient 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 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 2.

Table 2: Tests on 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	

The binding properties of the waste plastics is an indicator that it can be used to bind aggregate particles together without release of gases at melting temperatures.

2.1.4 Sisal Fibre

Sisal fibre was tested for various properties as indicated in Table 3.

Table 3: Properties of sisal fibre.

Properties of Sisal Fibre Tested	Values	Permissible Values
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 3. The sisal properties of strength and strain implies that sisal fibre can be used as a stabilizing additive in preparation of asphalt concrete, where they can hold aggregates and bitumen into a firm matrix.

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 treated sisal fibre 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.

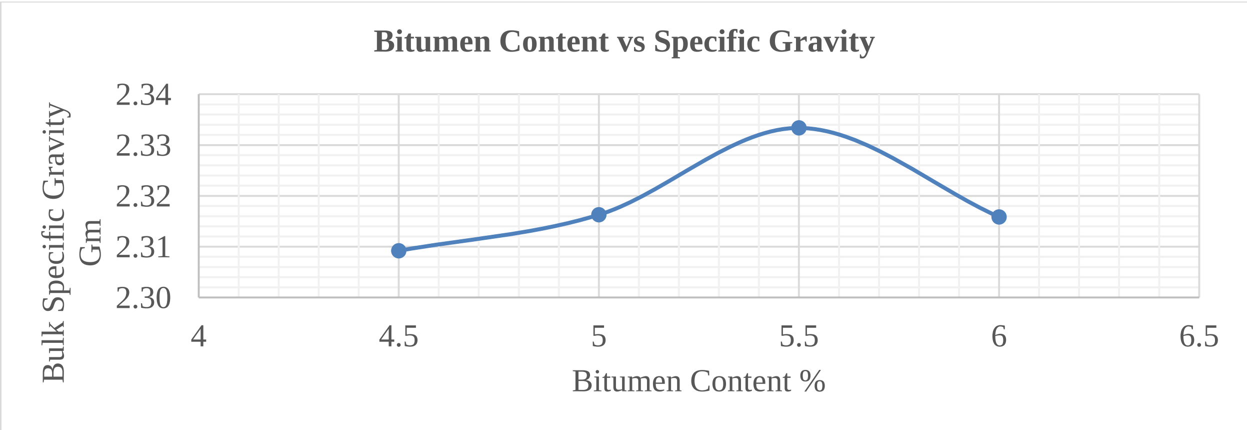

Figure 2(a): Bitumen content vs density of mix.

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.

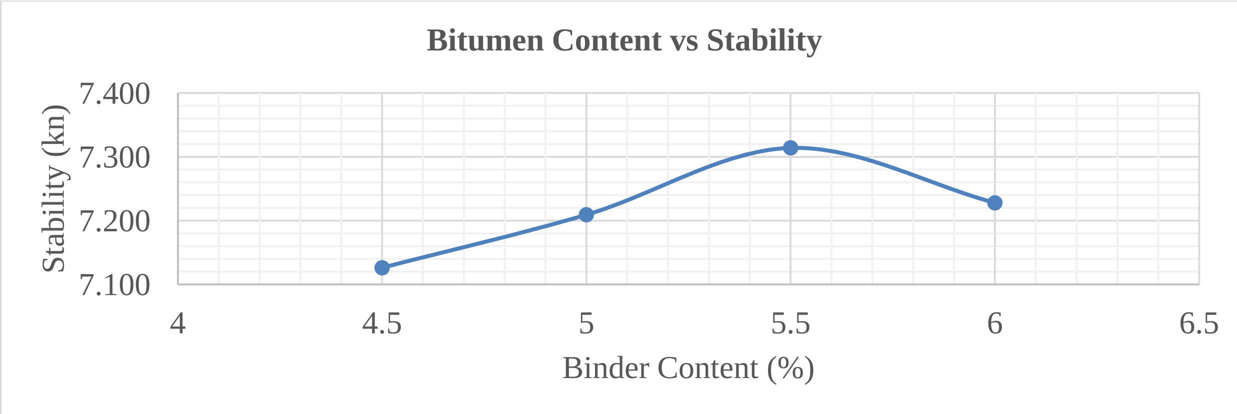

Figure 2(b): Bitumen content vs stability.

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.

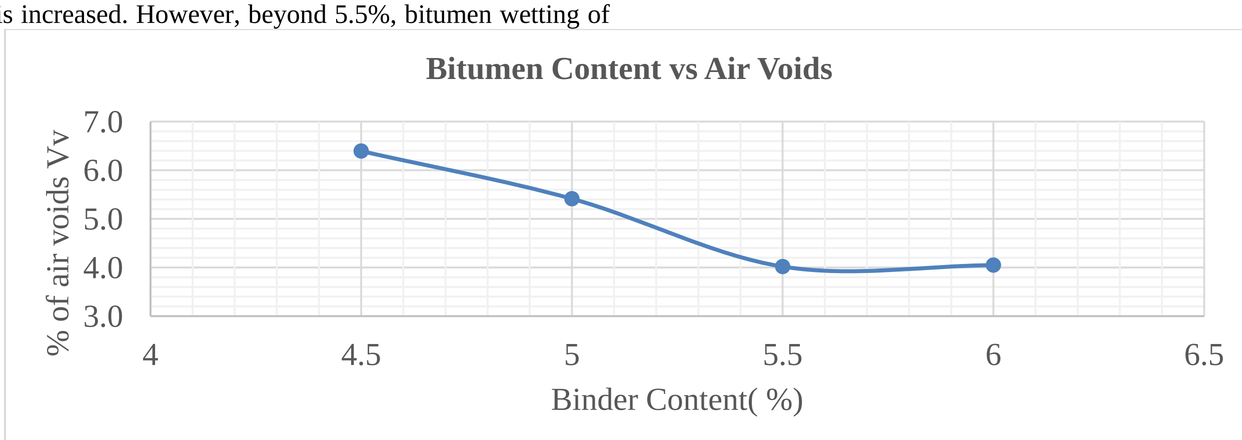

Figure 2(c): Bitumen content vs % Air voids

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 ofg 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

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

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 of the modifier.

Results of drain down at various percentages of additive contents are given in Tables 4(a), 4(b) and Figure 3(a) and 3(b). From Tables 4(a) and 4(b), it can be observed that all additives provide significant stabilization to the mixture as compared to the control mixture. Drain down of the control mixture is 6.5% which is beyond the specified limits as per AASHTO T305 (not to exceed 0.3% by weight of mix). It is evident that in all stabilized OGA mixtures, the values of drain down decreases considerably with increase in additive content and reaches the acceptable limit at 0.3 % sisal fibre (SF) content and 5% waste plastic (WP) content. This indicates that in all mixtures, each additive is performing its function as a stabilizing additive. The potential effects of the inclusion of additives in OGA mixtures are therefore beneficial in preventing the bleeding phenomenon of the mixtures and the drain down of this gap graded mix having rich binder content.

Either sisal fibre or waste plastics additive can be effectively utilized as the stabilizing agent. Fibre stabilizers are found to be more effective in reducing the drain down than waste plastics stabilizers due to the absorptive nature of fibres.

Table 4(a): 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 4(b): 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

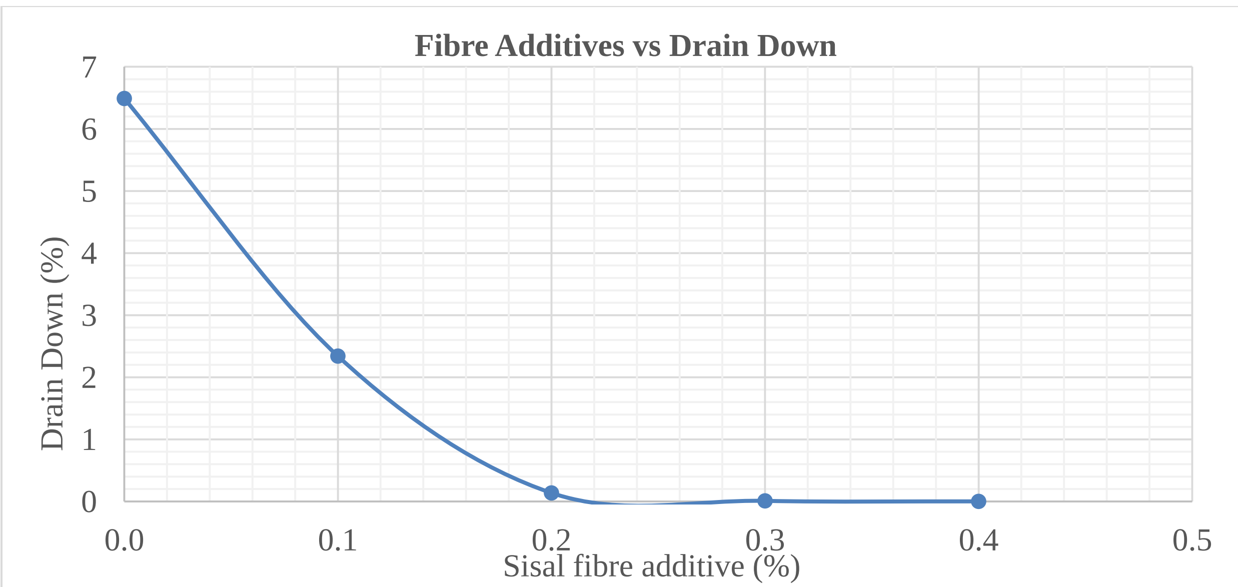

Figure 3(a): Variation of drain down with different percentages of SF.

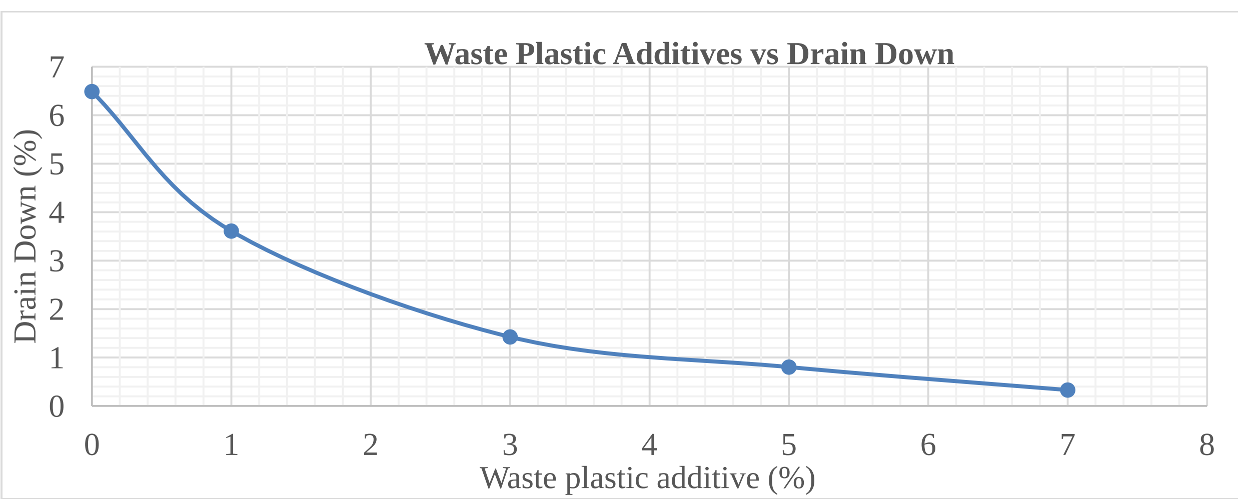

Figure 3(b): Variation of drain down with different percentages of waste plastics.

3.3. Stabilizing Capacity of Sisal-Plastic Compared to Other Additives

There are some differences in the performance of each additive at binder contents greater than the optimum binder content. Drain down is also tested to determine the stabilizing capacity of each additive. The drain down for mix with no additives was more compared to mixtures with additives as shown in Figure 4. It is observed that, when 0.3% of fibre is used together with 5% of waste plastics, the bitumen retention by waste plastics was greatly improved compared to other samples.

The sisal fibre and sisal-plastic additives have a much higher stabilizing effect, which can be attributed to the absorptive nature of the fibres compared to the waste plastics. The fibres firmly bind the aggregate particles inside the matrix and prevent them of movement, which makes the mix stiffer.

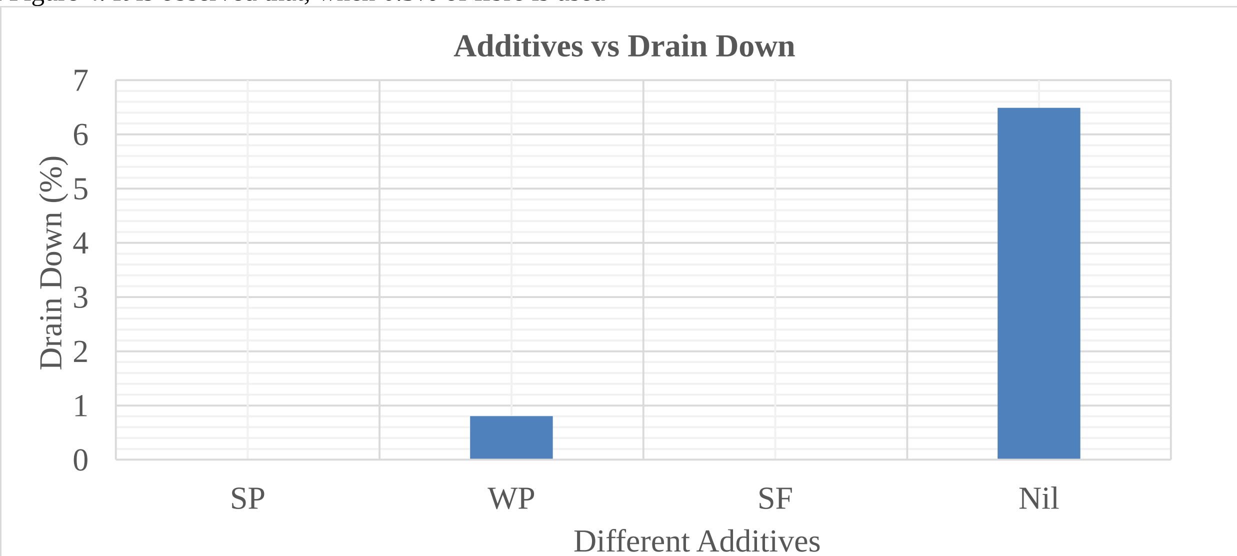

Figure 4: Drain down results for different additives

IV. Conclusion

From the drain down study of the OGA mixtures, it can be concluded that the additives used in the OGA acts as effective stabilizing agents. The combination of Sisal Fibre (SF) and waste plastics (WP) improves the bitumen retention property of OGA stabilized with Waste Plastics. The drain down was found to be 0% for Sisal-Plastic modified samples as compared to 6.5% for control mix and 0.8% for waste plastic modified samples. The role of additive is to stiffen the mastic and thereby reducing the drainage of the mixture at high temperatures during storage, transportation, placement and compaction of OGA mixtures. Sisal-plastic modified open graded asphalt showed the best bitumen retention compared with OGA stabilized with Waste Plastics.

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