ANALYSIS OF BITUMEN DRAINDOWN CHARACTERISTICS OF SISAL-PLASTIC MODIFIED OPEN GRADED ASPHALT

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Abstract
A study was done to determine the feasibility of improving bitumen retention of open graded asphalt (OGA) concrete through the use of sisal fiber and a blend of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) type of waste plastics. Open graded asphalt concrete is made of gap graded aggregate whose sizes range from 6mm to 12mm. The main objective of this research was to determine how sisal fibre can be used to reduce bitumen draindown and effectively utilize waste plastics in construction of flexible pavement to improve strength and performance capabilities. 5mm long sisal fibre of varying proportion percentage ranging from 0.1%, 0.2%, 0.3% and 0.4% were used in preparation of the samples. Further 2-3mm shredded waste plastic was varied from 0%, 1%, 3%, 5% and 7% in another set of asphalt concrete samples. The optimum percentage quantities of sisal fibre and waste plastics obtained at optimum Marshall stability were used in the determination of bitumen draindown. Aggregates were mixed with 5% waste plastics and heated at 170^{o}C until waste plastics coated the aggregates. Thereafter, 0.3% sisal fibre treated with sodium hydroxide (NaOH) was mixed with hot bitumen and coated hot aggregates at 170°C. The resultant mix was analyzed for bitumen retention properties to assess its suitability for road construction. The draindown was found to be 0% for Sisal-Plastic modified samples as compared to 6.5% for control mix. The adoption of the findings of this study will lead to improved road pavement strengths that can bear increasing traffic loads without rutting or cracking. Utilization of waste plastic will help to improve the environment through friendly disposal of waste plastics.

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

1.0 Introduction

Open graded asphalt (OGA) is a hot mix asphalt (HMA) with less fines compared to dense graded asphalt concrete. Hence, they have high bitumen draindown due to large pore spaces between the aggregate particles. This type of asphalt concrete is used as wearing course in pavement construction so as to provide more safety in wet weather conditions, through reduced surface water and spray during rain. It also reduces traffic noise levels on a road pavement when there is traffic movement (Hamedi et al., 2017). Open graded asphalt is a porous gap graded asphalt mix whose aggregate sizes are 6/12mm and designed to provide large voids to allow surface water to drain away thereby improving the safety of the motorist. Problems associated with OGA mixtures are bitumen draindown and bleeding during storage, transportation and placement due to large internal voids (Kar, 2012). However, 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 are added to stiffen the mastic thereby reducing the bitumen draindown at high temperatures. This enables retention of bitumen binder contents for increased durability (Kamraj et al., 2006). OGA mixtures exhibit a very high bitumen binder film thickness of 5-7% by weight of mix. This high binder content and the filler content compared to that of dense-graded hot mix asphalt, lead to higher susceptibility for the bitumen binder to drain off the aggregate skeleton (Huang et al., 2007). Irregular distribution of bitumen binder due to its draindown 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, 2010; Mallick et al., 2000). Experimental observations have shown that plastics can be used to increase the Marshall stability, flow and permeability of asphaltic concrete when used as modifiers. However, they showed poor performance on bitumen drain down, bleeding and ductility (Haggam et al., 2014). Characterization tests performed on plastic modified asphalt concrete mixes showed that there was increase in toughness, hardness and stability by 64%, 18% and 75% respectively. The samples performed significantly well on compressive strength and permeability but showed low bitumen retention value of 20% and low tensile strength value of 21% (Sulyman, 2014). Therefore, using both sisal fibre and waste plastics in the modification of open graded asphalt will improve the Marshall stability, tensile strength and bitumen retention thus increasing the strength of pavement.

2.0 Materials and Methods

2.1 Materials

Materials used in this study are bitumen grade 80/100, graded aggregate of nominal size 6/12mm, treated sisal fibre of 0.1 to 0.4 mm diameter and 2-3mm shredded waste plastics. Bitumen was sourced from Colas E.A., sisal fibre were bought in Kitui, and waste plastics were collected from Dandora while aggregates were sampled from Halai ltd in Mulolongo, Machakos County.

2.1.1 Aggregates properties

The aggregates were graded to conform to varying sizes of 6-12 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 – 19
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 1097-8:2020**
5	Specific Gravity	2.72	2.5-3	BS EN 1097-6:2013

The results for grading of aggregates were presented in Figure 1. It was observed that fine particles were 30% while coarse particles were 70% of the total mix. Thus, the composition ratio of course aggregates and fines are 70:30. The grading results were found to be within the OGA percentage grading range according to ASTM C136/C136M – 19. 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.

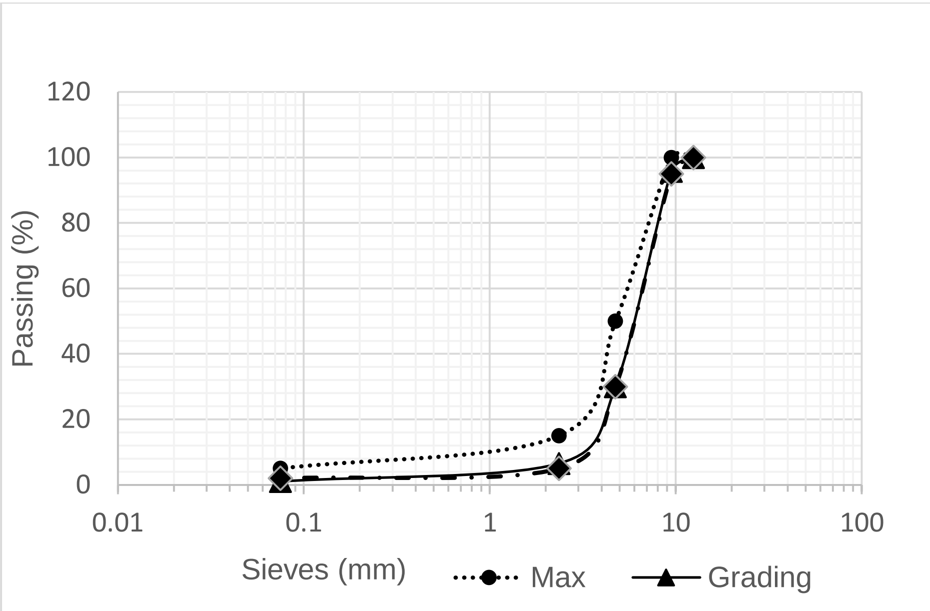

Figure 1: Grading curve for 6/12 mm aggregate for OGA mix.

The aggregates' average impact value (AIV) and average crushing value (ACV) were 27% and 26% respectively as recorded in Table 1. The values are within the standard (BS EN 1097-2:2010) requirement of less than 30%. It means that the aggregates have sufficient toughness to resist their disintegration due to impact. Movement of vehicles on the road surface subjects aggregates to impact which breaks them down into smaller pieces. Aggregates with recommended impact value (AIV) and average crushing value (ACV), means that the aggregates are resistant to crushing under a gradually applied compressive load caused by traffic loads. Which makes it suitable for road construction. The abrasion value of 28% is within the standard BS EN 1097-8:2009 requirements of less than 30% for bituminous mix. Abrasion test was carried out to test the hardness property of aggregates and to decide whether they were suitable for different pavement construction works. The aggregates were found to be hard and therefore resistance to further disintegration as a result of traffic loads. The aggregates' specific gravity of 2.72 and 0.85% water absorption means that the aggregates meet the requirements of the standard BS EN 1097-6:2013 which specifies specific gravity range of 2.5-3 and water absorption value of less than 2%. Therefore, the aggregates are not porous, which is indicative of less bitumen absorption. When less bitumen is absorbed, more of it is utilized in binding the aggregate particles together forming a strong bond.

2.1.2 Bitumen

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

Table 2: Salient properties of bitumen

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

The results obtained were as recorded in Table 2. Bitumen properties test results for penetration, softening point, ductility and specific gravity were within the requirements of the specified standards. Therefore, it was concluded that the bitumen was suitable to be used as a binder in the manufacture of asphalt concrete.

2.1.3 Waste Plastics

High-density polyethylene (HDPE) and low-density polyethylene (LDPE) mixed in equal proportions were shred to size 2-3 mm. Both plastics have binding properties that are suitable to modify asphalt concrete (Sultana et al., 2012). Their properties were determined by standard tests as given in Table 3.

Table 3: Tests on waste plastics.

S/No.	Test	Permissible Value	Test Value	Standard
1	Specific gravity	1.3-1.4	1.4	ASTM D792 – 20
2	Softening point	No gas release	No gas release at 100°-120°C	ASTM D1505-18

3	Binding properties	>10 N/mm^2	14 N/mm^2	ASTM D1505-18

The average specific gravity test results for waste plastics was 1.40. This value is within the permissible range of 1.3-1.4 (Soni and Punjabi, 2014). This means, the waste plastics have the ability to adequately coat the aggregate particles (Sultana et al., 2012). Specific gravity is an indirect measure of density. It is the most important parameter of quality of waste plastics which results in higher strength of the modified asphalt concrete. The test results showed that no gas released for temperature range of up to 120^{0}C as stipulated in standard ASM D1505-18. This means that the plastics can be melted at high temperatures of between 100-120^{0}C without emission of gases which could be hazardous to the environment by causing air pollution (Soni and Punjabi, 2014).

Melting the plastic wastes at high temperatures enables the molten plastics to penetrate the aggregate pores and adequately coat the aggregates. This results into higher strength of asphalt concrete. Hence, waste plastics are found to be suitable for use as modifier of asphalt concrete to enhance the strength. The binding property is an indicator of waste plastics ability to hold the aggregates together. Compressive strength of cubes made of aggregates coated with waste plastics increased with percentage increase in waste plastics up to 12.5% when the compressive strength was 14 N/mm^2. Waste plastics, when in molten state binds the aggregates together by forming a strong bond thus making asphalt concrete strong.

2.1.4 Sisal Fibre

The test results for properties of sisal fibre are recorded in Table 4. The sisal fibre diameter and density test results were 0.11mm and 1.33 g/cm^3 respectively. This implies that sisal fibre can be used as a stabilizing additive in preparation of asphalt concrete to hold aggregates and bitumen into a firm matrix. Moisture content and water absorption test results are within the permissible values (Sani et al. 2017). These properties indicate that the sisal fibre were properly processed and dried to produce fibres with the required water absorption which is necessary to reduce bitumen draindown.

Table 4: Properties of sisal fibre.

Properties of Sisal Fibre Tested	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
Water absorption (%)	98	85-135

Asphalt concrete modified using sisal fibre will reduce bitumen draindown during transportation and placement of hot asphalt concrete (Bindu et al., 2014). Reduction in loss of bitumen results in stronger pavements which can hold higher traffic loads compared to pavements constructed from non-modified asphalt concrete.

3.0 Laboratory Mix Design and Analysis

To determine the flow and stability, the following apparatus were used

(i) Marshall Stability apparatus.
(ii) Dial gauge.
(iii) Balance and water bath.

In the preparation of Marshall Stability test samples, required proportions of coarse aggregates, fine aggregates, filler and modifiers for modified samples were selected in such a way as to fulfill the required specification. The total weight of the aggregate in the mix was 1200g. The test procedure used to determine Marshall stability and flow of bituminous mixtures was as per standard AASHTO T 245-15 (Huang et al., 2007). The weighed aggregates and the bitumen were heated separately up to 170^{o}C and 163^{o}C respectively. For modified samples, plastics were heated together with aggregates. Sisal fibre was treated using sodium hydroxide solution (NaOH) at a temperature of 15-18°C. The fibre was immersed in a bucket of the solution for 12 hours, then removed and air-dried. Treatment of sisal fibre is necessary to reduce decomposition and increase fibre strength. The materials were mixed thoroughly and transferred to the compaction mould arranged on the compaction pedestal. For sisal modified asphalt concrete samples, heated bitumen and aggregates were mixed together with treated sisal fibre. For sisal-plastic modified samples, plastics heated together with aggregates were mixed with bitumen as treated sisal was being added. 75 blows were done on the top side of the respective mix sample with a standard hammer (45cm, 4.86 kg). The specimen was reversed and done 75 blows again. The mould with the specimen was taken and cooled for a few minutes. The specimen was removed from the mold by gentle pushing. The respective specimens were marked and cured at room temperature, overnight. Before testing the samples, they were kept in the water bath at 60^{o}C for half an hour. The stability and flow of the samples were checked on the Marshall apparatus by loading to attain maximum load. The dial gauge was read for flow test result. Graph plot of percentage of bitumen content on the x-axis and stability on the y-axis was done to get maximum Marshall stability of the bituminous mix. Dial gauge reading at the attained maximum load was taken for flow test result. The average of three tests were calculated as the mean value for the flow.

3.1 Determination of optimal bitumen content

Three samples each of open graded asphalt (OGA) concretes were prepared for each bitumen content varied from 4.5% to 6% of total weight of corresponding sample and results are presented in Figures 2(a), 2(b) and 2(c). Specific gravity increases with increase in percentage of bitumen up to 5.5% of bitumen content and then drops with increase in bitumen content (Figure 2(a)). Marshall stability of the asphalt concrete samples increased to a maximum value of 7.314kN with increase in bitumen content up to 5.5% (Figure 2(b)). This means that as bitumen content increased, the binder held the aggregate particles firmly together. The bond between the aggregates became firm as bitumen content increased up to optimum bitumen content of 5.5%, where further increases resulted into loose bonds.

The excess bitumen increased wetting condition around the aggregate particles causing weak bonds by reducing cohesion between the particles. Flow increased with increase in binder content. This means that as bitumen content was increased, bitumen coated the aggregates, which reduced the friction between the aggregates. The volume of the sample increased as bitumen was further added since it had filled all the spaces between the aggregates. Thus, the voids decreased with increase in bitumen content which results into pavement bleeding and rutting when excess bitumen is used.

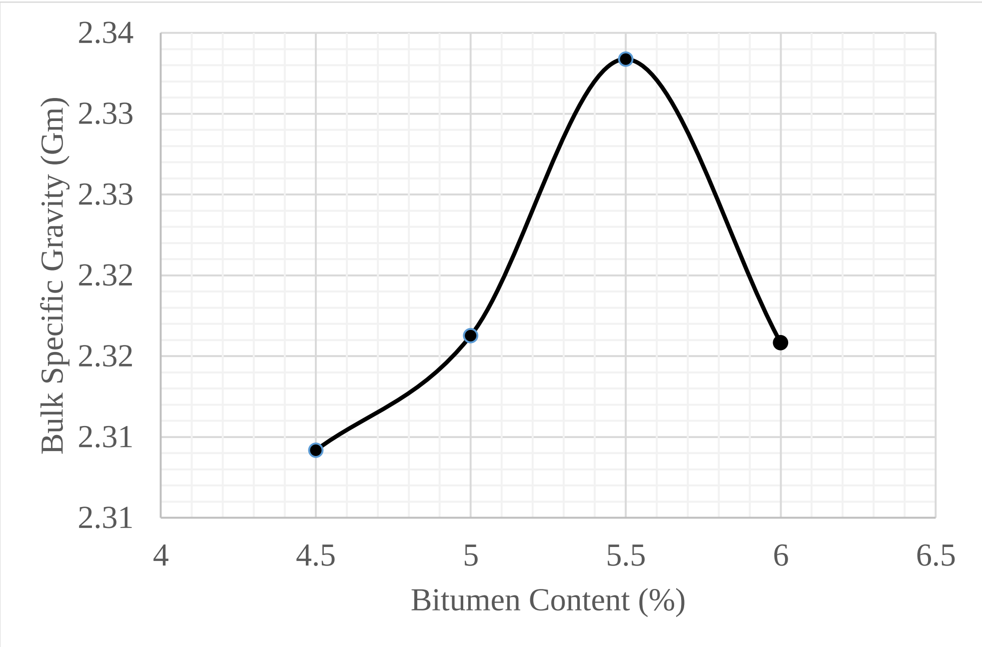

Figure 2(a): Bitumen content vs density of mix.

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.

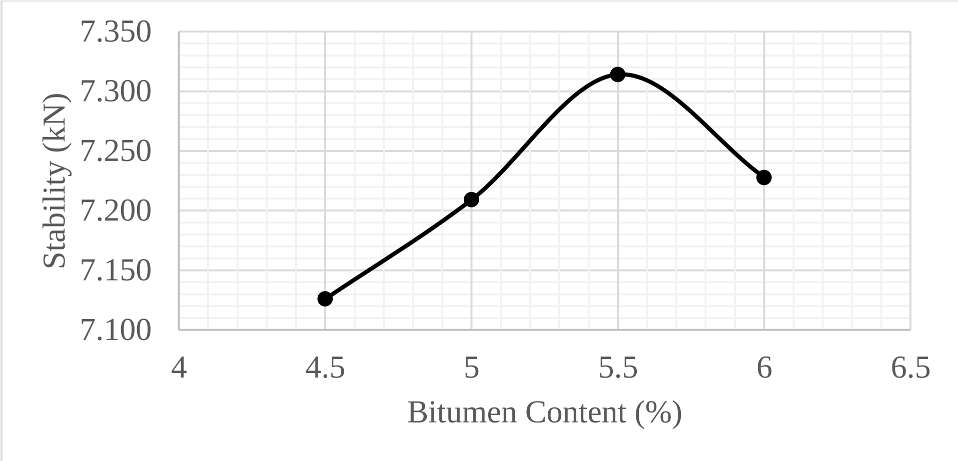

Figure 2(b): Bitumen content vs stability.

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.

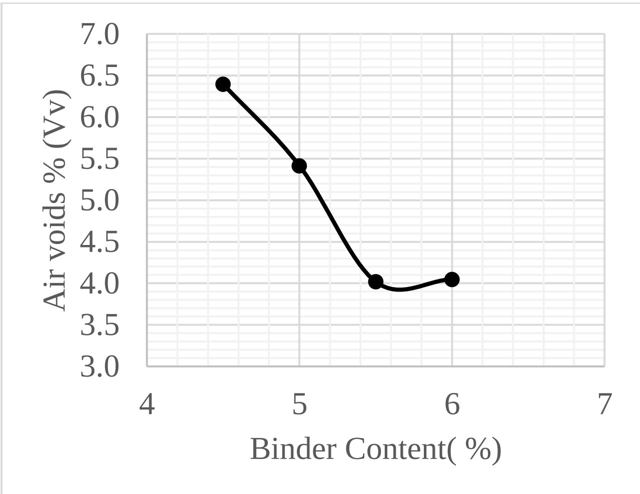

Figure 2(c): Bitumen content vs % Air voids

Figure 2(c) shows the variation in percentage air voids of the mix at various bitumen content. It was observed that 4.02% air void was achieved at 5.5% of bitumen content. Air void 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. Optimum bitumen content is the mean bitumen content at maximum specific gravity, stability and minimum air voids as calculated using equation 3.1 below.

$\boldsymbol{B_0} = \frac{\mathbf{5.5+5.5+5.5}}{\mathbf{3}} = \mathbf{5.5}\%$ . . . .Eqn 3.1

Bitumen content, 5.5% was used in the subsequent studies to determine bitumen draindown of asphalt concrete modified using sisal fibre and waste plastics.

3.2 Draindown 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 test Procedure used in the determination of bitumen draindown was done as per ASTM D6390-11. The uncompacted asphalt concrete mix was placed in a wire basket which was positioned on a pre-weighed dry paper plate. The entire apparatus was placed in a forced draft oven for one hour at 177°C. After 60 minutes, the basket containing the concrete sample was removed from the oven along with paper plate. The paper plate was weighed to determine the amount of bitumen draindown that occurred. Draindown was calculated as 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 draindown of the modifier. Results of draindown at various percentages of additive contents are presented in Figure 3(a) and 3(b). It was observed that bitumen draindown reduced from 6.5% to 0% as the proportion increase in percentage sisal fibre content increased from 0% to 3%. When waste plastics were used to modify the asphalt concrete, bitumen draindown reduced from 6.5% to 0.8% as the proportion increase in percentage waste plastics content increased from 0% to 5%. The additives provide higher stabilization to the modified asphalt concrete mix in comparison to the control mix without modifiers. Draindown of the control mixture was 6.5% which is beyond the specified limits 0.3% as per AASHTO T305. However, at 0.3% of sisal fibre modified asphalt concrete sample, bitumen retention was 0% compared to waste plastics modified asphalt concrete whose bitumen retention is 0.8%. Effects of the inclusion of sisal fibre and waste plastics in the mixtures prevented the bleeding phenomenon of the asphalt concrete mix and bitumen drain down. Sisal fibres stiffen and hold bitumen around the aggregates in the mix. The coating of aggregates using plastics reduces the bleeding phenomena by holding the bitumen in the mixture. This produces a strong road pavement which resist rutting, cracking and bitumen blending.

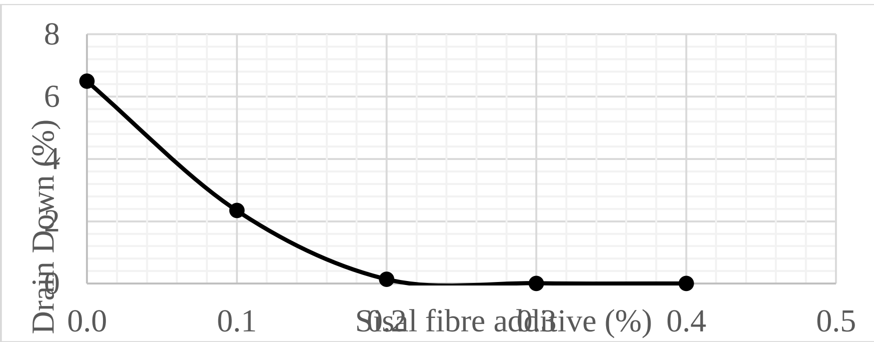

Figure 3(a): Variation of draindown with different percentages of sisal fibre.

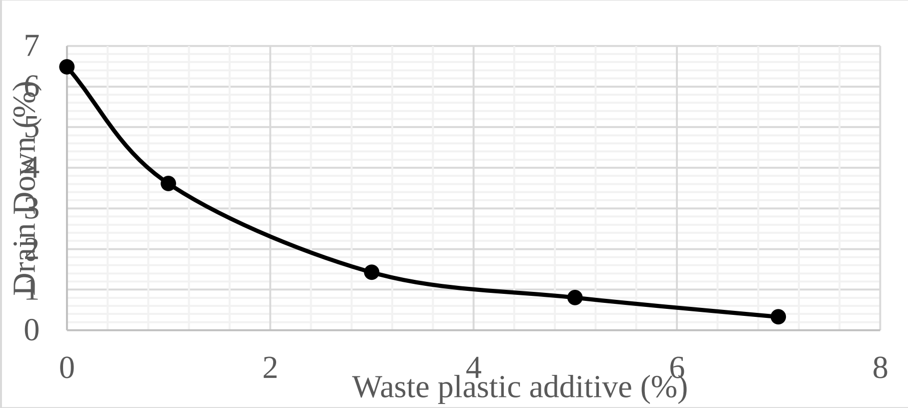

Figure 3(b): Variation of draindown with different percentages of waste plastics.

3.3. Bitumen retention of sisal-plastic modified open graded asphalt

To evaluate the effect of combination of sisal fibre and waste plastics on asphalt concrete, 0.3% sisal fibre and 5% waste plastics were both used to modify open graded asphalt concrete. These percentages of modifiers were selected because they were optimum contents when asphalt concrete had highest strength as found out in another research to determine the effect of sisal-fibre in the stability of asphalt concrete, carried out by the same authors. Bitumen drain down test results for sisal-plastic modified gap graded asphalt concrete are presented in Figure 4. The bitumen draindown for control asphalt concrete control mix was 6.5%. When 0.3% sisal fibre was used to modify the asphalt concrete, bitumen loss was 0%. However, when 5% waste plastics were used to modify the asphalt concrete, the bitumen loss was 0.80%. Further when 0.3% sisal fibre and 5% of waste plastics were both used to modify the asphalt concrete, the bitumen loss was 0%. This means that sisal fibres have strong stabilizing ability as compared to waste plastics due to the absorption ability of sisal fibres. Sisal fibres and waste plastics bind the aggregates to make a firm and stiff asphalt concrete mix. This enhances bitumen retention and reduces bleeding.

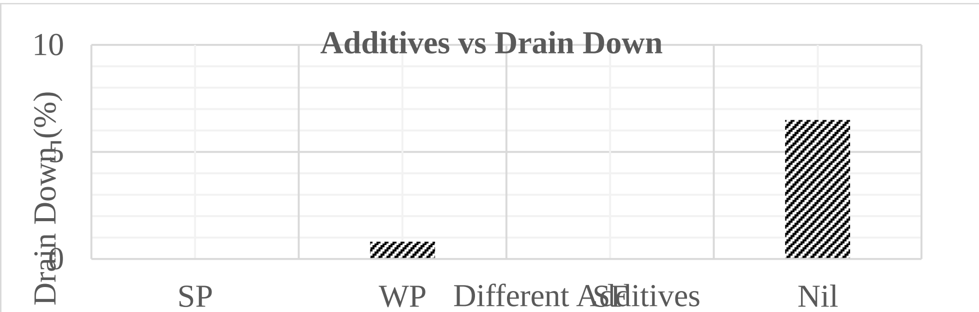

Figure 4: Draindown results for different additives

4.0 Conclusion

From the draindown 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 waste plastic stabilized asphalt concrete. The draindown 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. Hence, sisal-plastic modified open graded asphalt showed the best bitumen retention at 0%. This was possible because sisal fibre when combined with waste plastics stiffed the asphalt concrete, thereby reducing bitumen draindown at high temperatures during storage, transportation, placement and compaction. Road pavements that are constructed using sisal-plastic modified asphalt concrete mixes have sufficient strength to withstand traffic load without cracking and rutting since bitumen that could be lost is retained to bind the aggregates to form a firm matrix together with sisal fibre and waste plastics.

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