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Revolutionizing roads: Exploring crumble rubber and sisal fibers for sustainable asphalt solutions

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Abstract

This research aims to investigate the stability of asphalt mixtures using crumble rubber and sisal fiber mixes. Common laboratory tests were performed on the modified bitumen asphalt mix using various proportions of CR-SF and thus analyzed. The Marshal Mix design procedure was used to determine the Optimum Bitumen Content (OBC) and test the modified mixture properties.

Hot Mix Asphalt (HMA) is a particulate composite material consisting of mineral aggregates, asphalt binder, and air voids. Asphalt binder is considered the most expensive and economically variable material. The increase in energy cost, the need for improvement of pavement quality, and Environmental concerns force the researcher to find alternative materials to modify the properties of ASPHALT binder. For this research, 16 samples were used to determine the OBC, and the remaining were used to investigate the effects of adding different CR- SF percentages to the asphalt mix. The OBC was 5.5 % by weight of the asphalt mix. Seven proportions of CR: SF by weight of OBC were tested (0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1%, and 15%:0%) besides testing of ordinary asphalt mix. Tests include the determination of stability, bulk density, flow, and air voids. Results indicated that CR: SF can be conveniently used as a modifier for asphalt mixes for sustainable management of crumble rubber waste and for improved performance of asphalt mix.

CR: SF content of 5 %:0.7% by weight of OBC is recommended as the optimum CR: SF content for improving the performance of the asphalt mix. Asphalt mix modified with 5.5%:0.7% CR: SF by OBC weight has approximately 40% higher stability value compared to the conventional asphalt mix. Asphalt mix modified with higher percentages of CR: SF exhibits lower bulk density, higher flow, and higher air voids.

Keywords: Hot Mix Asphalt; Sisal fiber; Optimum Binder Content; Indirect Tensile Strength Test; Marshal Mix design; Rutting Resistance.

1. Introduction

Road networks are mainly classified into two categories: namely, flexible pavements and rigid pavements. Flexible pavements are more widely used compared to rigid pavement due to advantages such as low initial cost, good resistance to temperature variation, easy repair work, and easy-to-locate underground works [1].

Throughout the last decades, there has been a rapid increase in traffic loading intensity in terms of the number of axles and large tire pressures caused by weighty vehicles. This rapid growth leads to some undesirable distresses in pavements such as rutting (permanent deformation) under the influences of repeated vehicle loading at high

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temperatures, low-temperature thermal cracking, and freeze-thaw cycles [2,3,4,5], which decrease the ride quality and service life of road pavements [6]. Therefore, technologists are always trying to enhance the properties of asphalt pavement mixes, where any extension in the service life of road pavements will be of course a great benefit to the economy [7].

Asphalt, or asphalt mixes modified with additives, is the most commonly applied approach to save natural resources and improve pavement performance when the asphalt produced does not meet the weather, traffic loads, and pavement structure requirements [8, 9].

Several types of additives can be used as a single additive or composite reinforcement in an asphalt mix. For more knowledge, most of the literature revealed that a single additive cannot improve all the performances of pavement asphalt mixes at the same time. As an example, asphalt binders with additives like crumb rubber, polymers, and natural rubber have been used to resist rutting at high temperatures and raveling in asphalt mixes. However, the problem of low-temperature cracking persists. On the other hand, the fibers can improve fatigue life by increasing the resistance to low-temperature cracking [10,11]. Thus, the use of double additives may improve the overall performance of asphalt mix, but most of the researchers are focused on the single modification and the composite reinforcement is still in its premature stage [12].

The main purpose of this study is to experimentally investigate a new compound of waste disposal materials (a combination of CR and SF) to modify the stability of asphalt. From an environmental and economic viewpoint, the use of CR and SF as bitumen modifying agents contributes to solving a waste disposal problem.

1.1 Statement of the Problem

The most dominant mode of transport in Ethiopia is road transport, including passenger traffic and freight transport. In Ethiopia, the flexible pavement type of construction is preferred over the rigid pavement type of construction due to its various advantages such as low initial cost, maintenance cost, etc. Despite the prominence of surface transport, most of the roads are poorly managed and badly maintained. Bitumen has been used as a binder and waterproofing material for the construction of roads, pavements, and airfield surfacing for several years. The demand for bitumen has increased tremendously because of rapid urbanization in recent years. The objective can be achieved by enhancing the durability of existing road surfacing which will result in reducing maintenance and resurfacing operations.

Over the past 15 years, the Ethiopian government has invested a huge amount of money in the field of road construction to reach excellent pavement performance. However, these roads show early signs of distress such as rutting and fatigue cracking. The pavement distress is due to changes in weather and high traffic loads. Environmental conditions and heavy loads directly affect the durability and pavement performance. Modified bitumen is one of the different solutions for pavement distress. A better understanding of the rheological properties of binders strengthens the ability to produce durable asphalt concrete pavements and to increase pavement life. Conventional ways of road construction have been experiencing problems of premature failure of pavements like potholes, roughness, and cracks which leads to poor performance of roads and their life. Modified bitumen will have the advantage of higher resistance to deformation at elevated pavement temperature, better aging resistance properties, higher fatigue resistance, better adhesion between aggregates and binder, prevention of cracking, and overall improved performance in extreme climatic conditions and under heavy traffic conditions. The performance of roads with regards to readability and roughness is known to have a significant cost implication to road users in terms of operational cost, in addition to affecting their safety and comfort. Permanent deformation in paved roads can be attributed to various factors such as the pavement structure, quality of individual constituent pavement materials, magnitude and regime of loading, environmental factors, such as moisture temperature, and others.

This study was conducted to investigate the possible use of CR: SF as an additive of hot-mix asphalt and to review the feasibility of incorporating CR: SF to improve the performance of the asphalt mix.

1.2 Objectives of the Study area

- General Objective

The purpose of the study is to investigate the stability of asphalt mixtures using crumble rubber and sisal fiber mixes.

- Specific Objective

To Study the behavior and properties of asphalt mix (stability, plastic flow, stiffness, voids).

To compare the performance of unmodified and CR: SF modified asphalt mix.

To select the optimum percentage of sisal fibers and rubber to be blended with commonly used bitumen to produce maximum compressive strength

1.3 Scope of the Study Area

The scope of the study is to evaluate the performance (flow, stability, void filled by bitumen, Void in total mix, density, optimum binder content) of the sisal fibers and crumble rubber is going be used as a mixture material in the asphalt mix design. The study covers modifying the asphalt mixtures by using sisal fibers and crumble rubber mixes. It is supported by different types of literature and a series of laboratory experiments.

2. Methodology

laboratory work had been obtained and analyzed to achieve study objectives which include studying the effect of adding different percentages of CR: SF on the mechanical properties of asphalt mix and identifying the optimum percent of CR: SF to be added to hot mix asphalt. The flow chart diagram below summarizes the overall methods, techniques, approaches, and materials used to carry out this research.

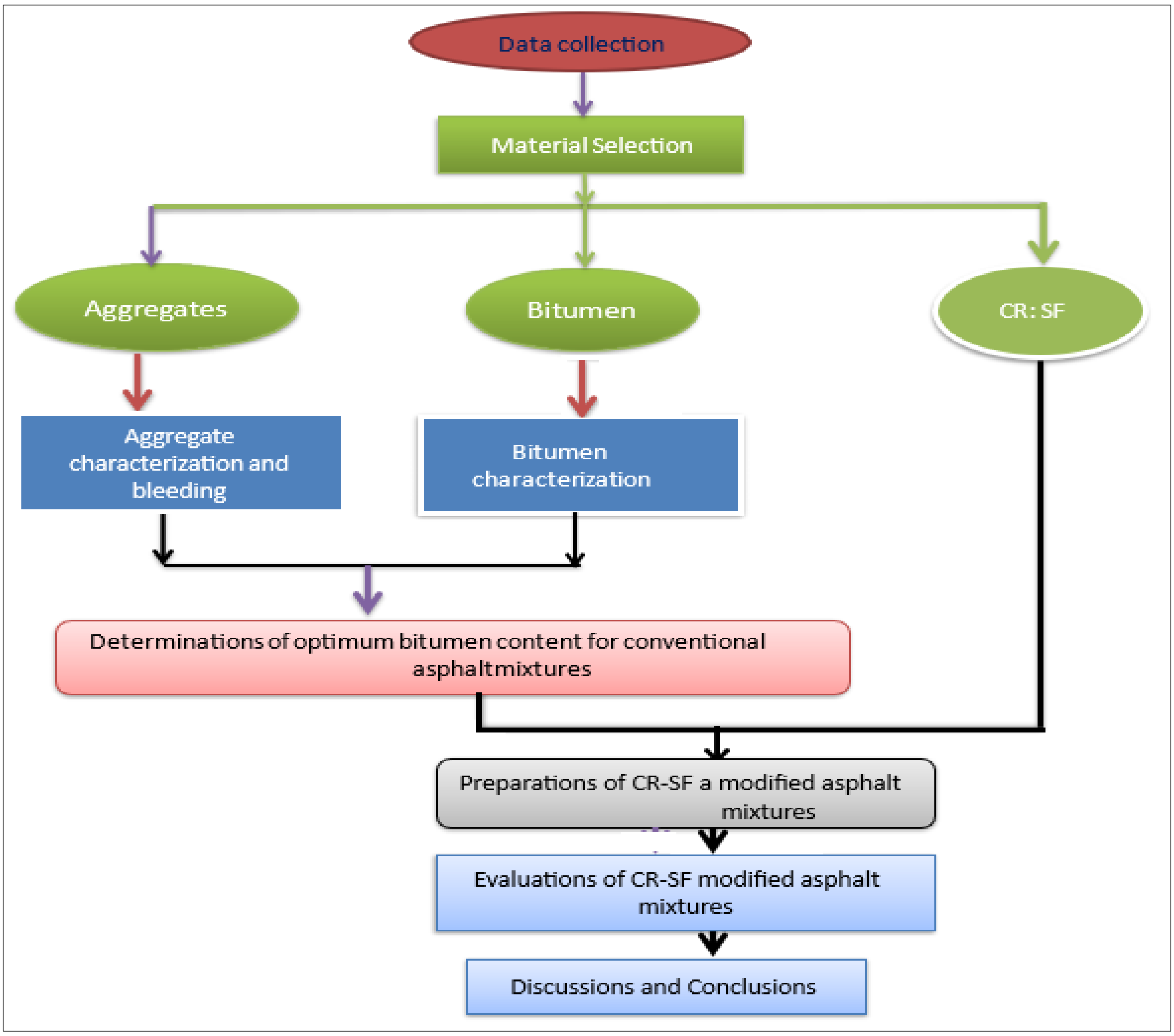

Figure 1 Schematic presentation of Methodology

2.1 Study Design

This research was designed to meet its objectives based on experimental findings.

- The first step in the research work was sample collection. At this stage, the samples of the component materials viz. crushed aggregate; bitumen, crumble rubber, and sisal fiber were collected.
- The second step was laboratory testing. This step comprises three major phases: First phase Quality testing, second-phase mix design, and third-phase moisture sensitivity Quality tests were undertaken on each component material so that their physical and chemical properties were identified. During the mix design phase, 18 types of mixtures were designed for determining OBC without any modifiers. The remaining twenty-eight mixes were composed of CR-SF at different percentages. The bituminous mixtures were tested and evaluated according to the Marshall method of mix design
- The third step of the research was the analysis and interpretation of the laboratory test data. In this step, the laboratory test data were analyzed and interpreted. This includes discussing the effects of CR-SF on the volumetric and Marshall properties of the mix. This includes the effect CR-SF has on Stability, Flow, unit weight, VTM, VMA, VFA effective asphalt content, and optimum asphalt content. The effect of the CR-SF on optimum asphalt content and the selection of an optimum CR-SF content are also discussed. Further, in this step, the bituminous mixtures were compared, based on the performance and volumetric properties of the normal mix and the three mixes to identify the cheaper option.
- The fourth and final step was a declaration of the research findings and recommendations based on those findings. The entire research process is shown in the flow chart in Figure 1 above.

2.2 Material Properties:

2.2.1. Aggregates

The aggregates used in the research were subjected to various tests to assess their physical characteristics and suitability for road construction. To produce identical controlled gradation, aggregates were sieved and recombined in the laboratory to meet the selected gradation which satisfied ASTM specifications for asphalt binder average gradation. The coarse and fine aggregate particles were separated into different sieve sizes and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515 for 19 mm nominal maximum aggregate size (NMAS).

Table 1 presents the physical properties of fine and coarse aggregates. The soundness tests were conducted by using Sodium Sulphate (Na_2SO_4) solution. The absorption characteristic of the aggregates is relatively high. This resulted in relatively greater consumption of bitumen in HMA.

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage. Gradation is usually measured by a sieve analysis.

Table 1 Aggregate physical properties

Types of Tests	Results	Specification (ERA, 2002)	Test Method
Los Angeles Abrasion (%)	13.00	< 30	AASHTO T96
Soundness (%)	4.57	< 12	AASHTO T104
Particle Shape, Flakiness (%)	21.06	< 45	BS 812, Part 105
Aggregate Crushing Value (%)	12.85	< 25	BS 812, Part 110
Sand Equivalent (%)	76.45	> 40	AASHTO T 176
Water Absorption (%)			
i. Coarse Aggregate	1.561	< 2	AASHTO T85-91
ii. Fine Aggregate	1.937	< 2	AASHTO T85-91
Bulk Specific Gravity			
i. Coarse Aggregate	2.68	N/A	AASHTO T85
ii. Fine Aggregate	1.94	N/A	AASHTO T84

Crushed aggregates were obtained from the crusher plant of the Deneba Crusher plant site in the Oromia region, Jimma Zone. The aggregates of each were sieved by dry sieve method and then mixed with different mix ratios to satisfy the ERA 2002 (Table 6400/8 Grading limits for combined aggregate and mix proportions for asphaltic surfacing) specification. The nominal maximum aggregate size (NMAS) and the maximum aggregate size (MAS) are found to be 19.0mm and 25.0mm respectively. Figure 2 shows the blended graduation of aggregate used in this study.

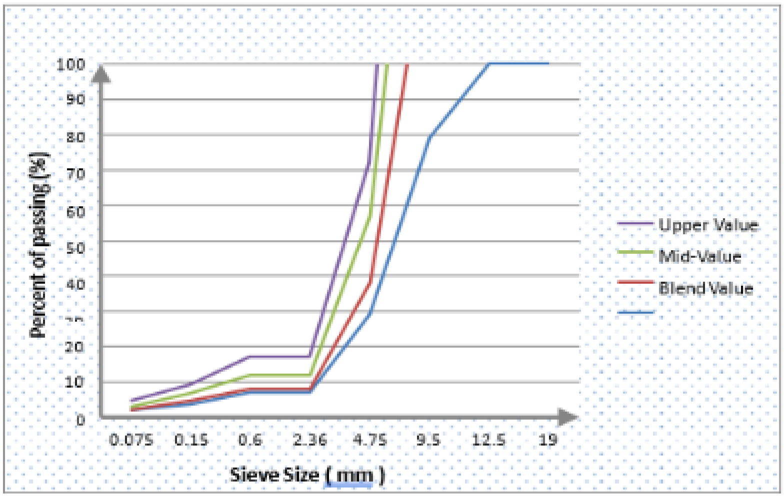

Figure 2 The blended graduation of aggregate used in this study

2.2.2. Bitumen

In this investigation, 60–70 penetration bitumen, obtained from Jimma Mineral Oil Refinery in Deneba, was used. The bitumen quality tests were conducted before the start of the mix design and compared to the specifications set in ERA 2013 PDM, AASHTO Standard Technical Specifications M20-70, and SABS-307. The results of the quality tests are presented in Table 2 below.

Table 2 Conventional rheological properties of the bitumen used in this study

Test	Standard ASTM	Value
Penetration (100g, 5 s, 25 ∘ C), 0.1 mm	ASTM D5-73	70
Softening point (∘ C)	ASTM D36-76	43
Ductility (25 ∘ C, 5 cm/min) (cm)	ASTM D113-79	>100
Flashing point (∘ C)	ASTM D92-78	>302

2.2.3. Crumble Rubbers

The rubber powder used for this study is the one prepared through the ambient procedure of cutting, scraping, and powdering waste. The rubber powder sifts through a No. 30 sieve (fiber and metals have been removed from the rubber) and its density is 1320 kg/m3. The granulated crumb rubber used is shown in Table 3

Table 3 Crumb rubber gradation used in this study

Sieve No.	Sieve size(mm)	%Passing
# 30	0.6	100
# 50	0.3	65
# 100	0.15	24
# 200	0.075	3

2.2.4. Sisal Fibers

Sisal Fiber used in this study was obtained from the market; SF was produced in pieces with an approximate dimension of 10cm*10cm. Then, the SF was taken into the laboratory and changed into small pieces by a hammer. The amounts of SF passing through #200 sieves are shown in Figures 3A and 3B. The chemical properties of SF are indicated in Table 4.

Table 4 Chemical compositions and physical properties of used sisal fibers

Sl.No	Chemical compositions		Physical property	
	Compositions	**Test Results**	**Property**	**Test Results**
1	Cellulose %	65	Density (gm/cc)	1.5
2	hemicellulose	12	Tensile strength (MPa)	511-635
3	lignin	9.9	Young's modulus (MPa)	9.4-2.4
4	waxes	2	Elongations at break (%)	2.0-2.5

Figure 3A Sisal fiber used

Figure 3B Sisal fiber plant

3. Results and Discussion

Results of laboratory work had been obtained and analyzed to achieve study objectives which include studying the effect of adding different percentages of CR: SF on the mechanical properties of asphalt mix and identifying the optimum percent of CR: SF to be added to hot mix asphalt. Laboratory work results are presented in three stages.

- First, handle the results of blending aggregates to obtain the asphalt-wearing course gradation curve.
- The second stage, the Marshal Test is carried out with different percentages of bitumen which are (4, 4.5, 5.0, 5.5, and 6.0%) and the results are analyzed to obtain the optimum bitumen content (OBC). After obtaining OBC,
- The third step is to study the effect of adding different percentages of CR: SF on asphalt mix properties which are (0%: 1%, 3%: 0.9%, 5%: 0.7%, 7%: 0.5%, 10%: 0.3%, 12%: 0.1% and 15%: 0%) by weight of bitumen.
- Marshal test results for modified asphalt mixes are analyzed and finally the optimum CR: SF modifier content is obtained.

As it was discussed various experiments need to be performed to reveal the physical and performance properties of the asphalt mixtures. Therefore, volumetric, stability and flow properties of mixtures were measured to evaluate the effect of HMA incorporation with dry process CR: SF modification.

3.1 Blending of aggregates

HMA is graded by the percentage of different-size aggregate particles it contains. HMA gradations which is the normal gradation used as a control for the study. Certain terms are used in referring to aggregate fractions: Course aggregate - G-1 ¾ inch, Coarse Aggregate -G-2, 3/8 inch, Fine Aggregate - G-3, Brick Mineral Filler & dust– G-4.

The final ratio of each aggregate material in the asphalt-wearing course is analyzed. The proposed aggregates gradation curve is found to be satisfying ASTM specifications for asphalt-wearing course gradation. The gradation of the final aggregate mix with ASTM gradation limits is presented in Figure 4.

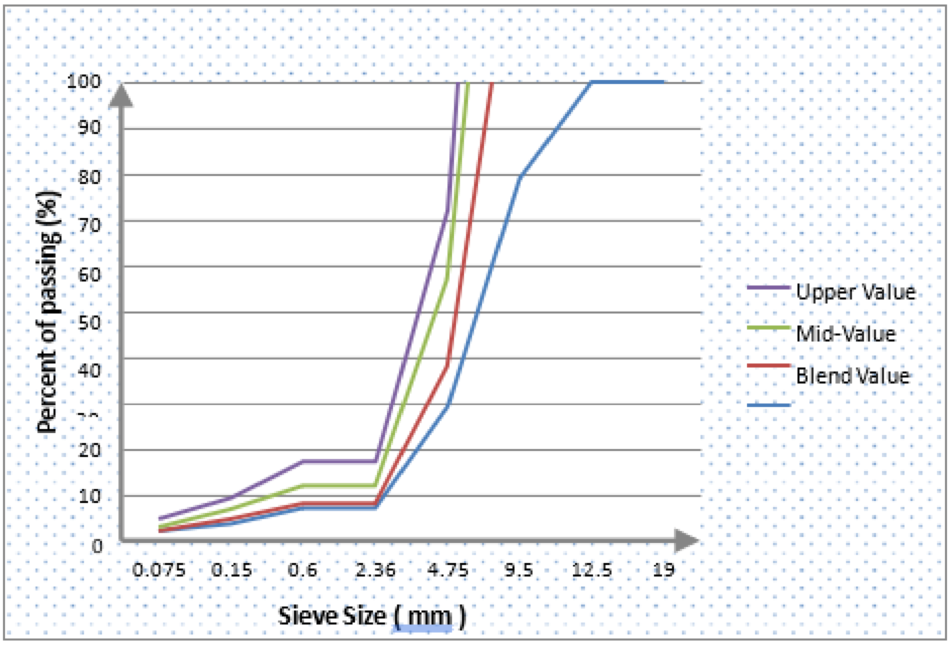

Figure 4 Gradation of final aggregates mix with ASTM specification range

3.2 Optimum Bitumen Content

It is considered that the effective asphalt content in the mixture determines the performance of mixtures. This can be explained as that it is the effective asphalt binder content that makes the asphalt film around the aggregate particles. If the asphalt film thickness around the aggregate particles is thick enough, various desirable characteristics such as better durability, more fatigue resistance, and higher resistance to moisture-induced damage can be achieved from bituminous mixtures. But, there should be a maximum limit where on an increase in temperature and loading, the asphalt content in the mix gets increased and results in bleeding on the surface of paved road. Table 5 and Figures 6 – 11 mentioned below show a summarised result of the marshal test.

Table 5 Optimum bitumen content determination of bituminous mixtures

AsphaltContent,(%)	Unit Weight,(mg/m^3)	Air Void, Va,(%)	VMA,(%)	VFB,%	Stability,(N)	Flow,(mm)
4.0	2.215	10.3	20.31	49.3	10.68	3.65
4.5	2.249	8.8	19.5	54.9	11.35	3.66
5.0	2.288	5.6	18.54	69.8	11.71	3.78
5.5	2.298	4.6	18.62	75.3	10.88	3.60
6.0	2.307	3.8	18.72	79.7	10.81	3.48

3.2.1. Stability Vs bitumen content relationship

The stability results for various bitumen contents are shown in Figure 5. The stability of the asphalt mix increased as the bitumen content increased till it reached the peak at bitumen content 5.0 % then it started to drop gradually at higher bitumen content.

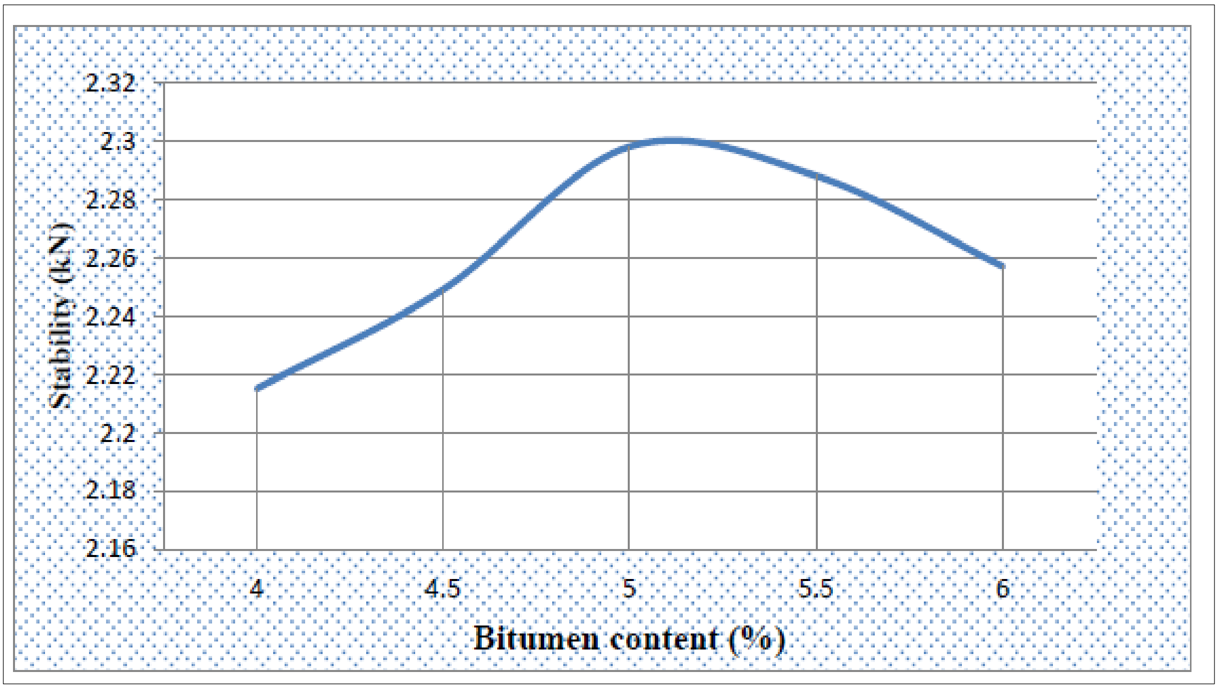

Figure 5 Stability vs. bitumen contents

3.2.2. Flow Vs Bitumen content relationship

Figure 6 displays the Flow results for different bitumen contents. Maximum bitumen content of 6.0% is the peak of the Flow of asphalt mix; with the Flow increasing gradually before this peak.

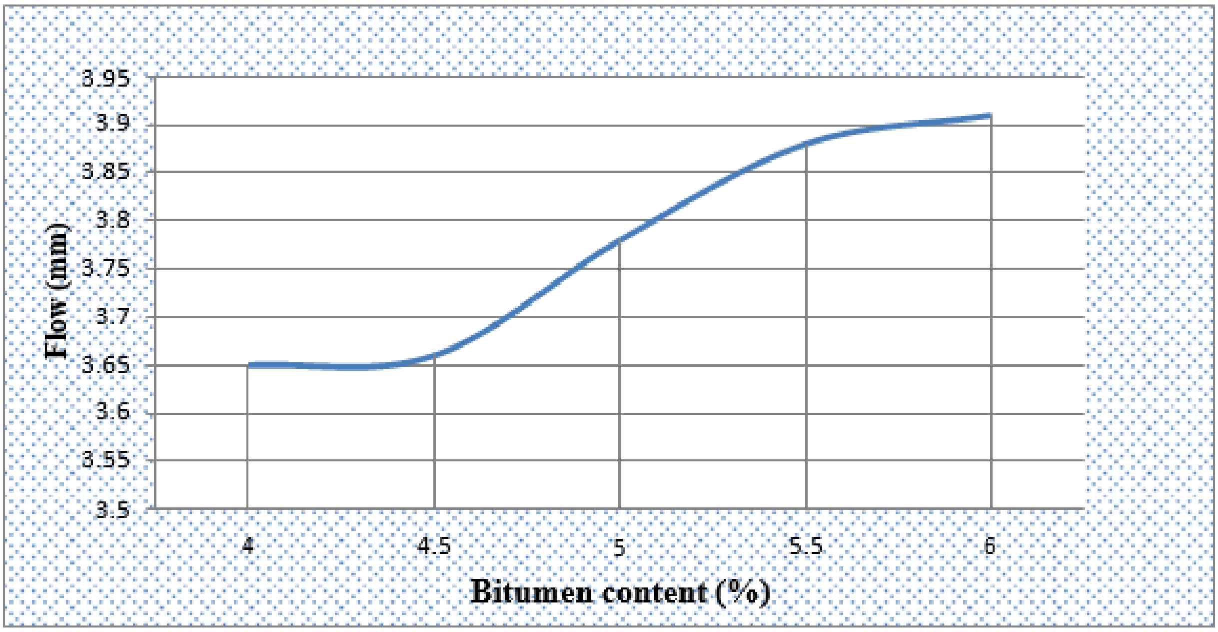

Figure 6 Flow vs. bitumen content

3.2.3. Bulk density vs. Bitumen content relationship

Bulk density is the real density of the compacted mix. Figure 7 displays the bulk density results for different bitumen contents are represented. The bulk density of asphalt mix increases as the bitumen content increases till it reaches the peak (2.298 g/cm3) at a bitumen content of 5.5 % then it starts to decline gradually at higher bitumen content.

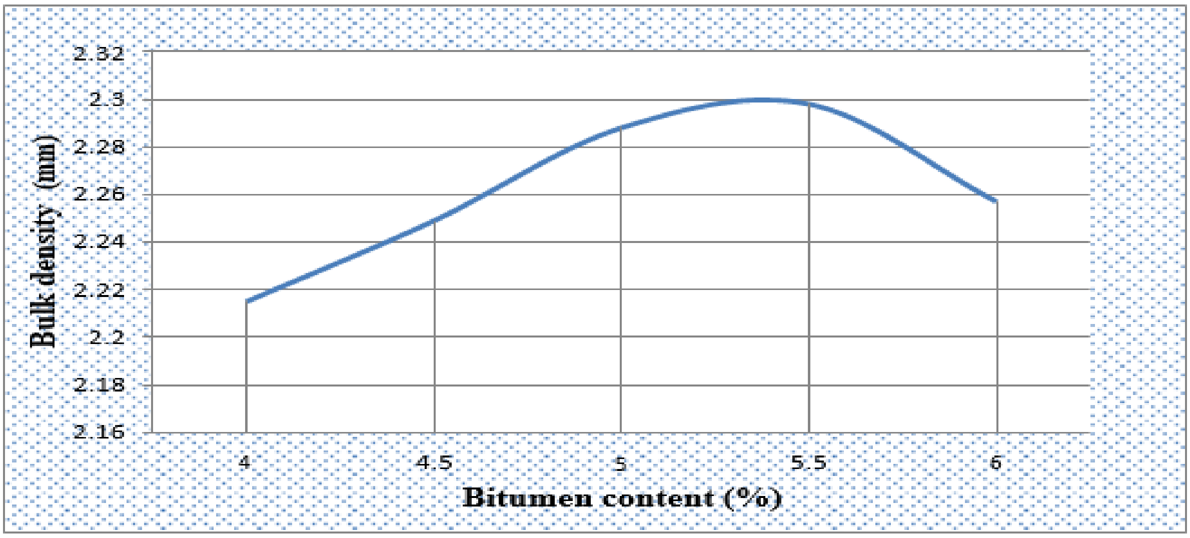

Figure 7 Bulk density vs. bitumen content

3.2.4. Air voids content Vs bitumen content relationship

Figure 8 displays the Va % results for different bitumen contents are represented. Maximum air void content value is at the lowest bitumen percentage (4.5%), Va % decreases steadily as bitumen content increases due to the increase of void percentage filled with bitumen in the asphalt mix.

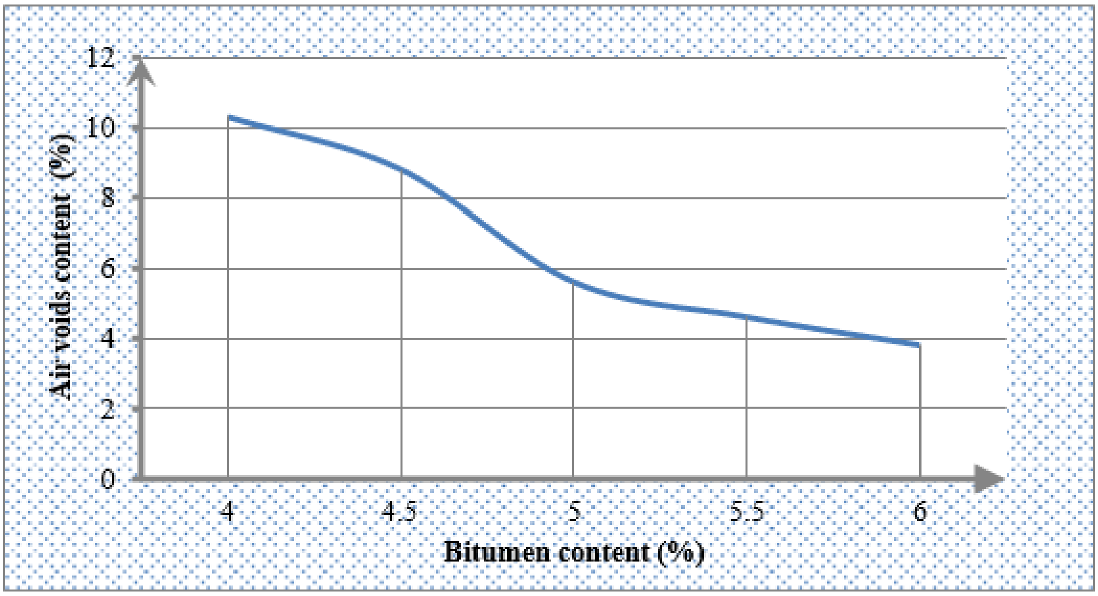

Figure 8 Mix air voids proportion vs. bitumen content

3.2.5. Voids Filled Vs Bitumen– bitumen content

Figure 9 displays the VFB % results for different bitumen contents are represented. The minimum VFB content value is at the lowest bitumen percentage (4.5%), VFB% increases steadily as bitumen content increases due to the increase of voids percentage filled with bitumen in the asphalt mix.

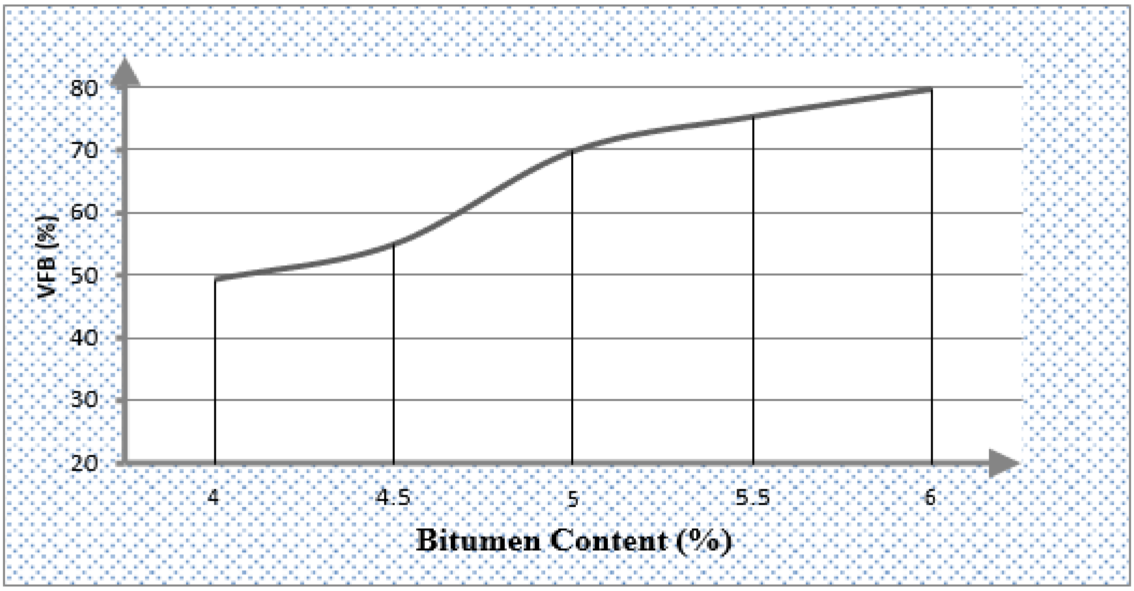

Figure 9 Voids filled bitumen proportion vs. bitumen content

3.2.6. Voids in Mineral Aggregates Vs Bitumen content relationship

Figure 10 displays the VMA results for different bitumen contents are represented. VMA decreases steadily as bitumen content increases and fills a higher percentage of voids in the asphalt mix.

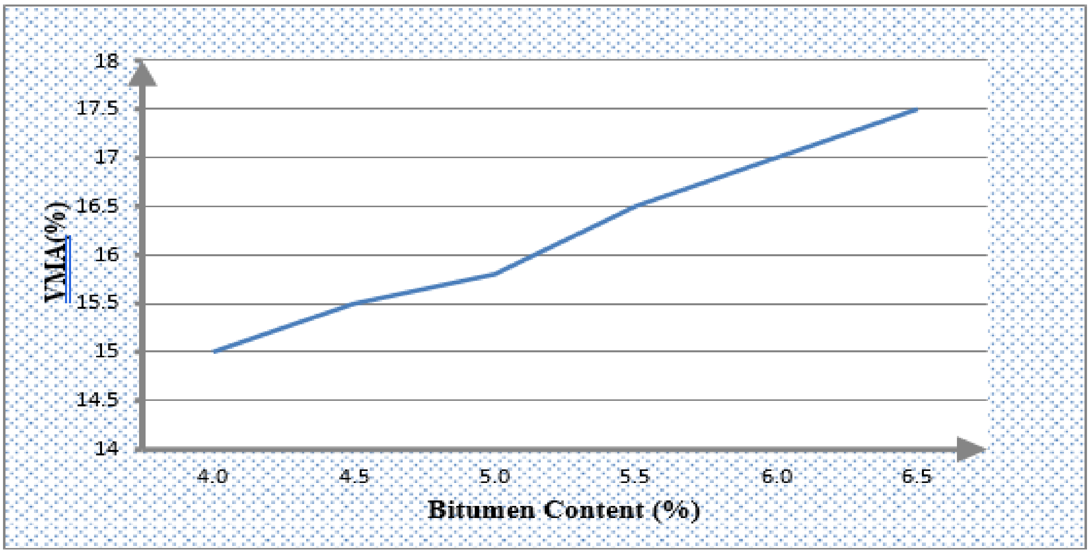

Figure 10 Voids of mineral aggregates proportion vs. bitumen content

3.2.7. Determination of optimum bitumen content (OBC)

After measurement of stability and Flow from the prepared specimen using the Marshall test (ASTM D 1559) it is common practice to select the design binder content by calculating the mean value of the binder contents for maximum stability, maximum density and the mean value for the specified range of void contents.

Compare values with the criteria for acceptability given in Table 6. The properties of the mix design at this design binder content with recommended Marshall Criteria are then analyzed. The optimum asphalt content value required to fulfill the Marshall requirement is 5.5%.

Table 6 Properties of the asphalt mix using optimum bitumen content

Property	Value	Mix Criteria	Range of bitumen content that satisfy the specific requirements
Stability (kg)	10.88	Min. 9KN	4.0 - 6.0
Flow (mm)	3.60	2-4mm	4.0 - 5.7
VMA (%)	18.62	10%-16 %	4.0 - 6.0
Va (%)	4.60	3%-6%	5.0 - 6.0

3.3 Effect of adding CR-SF on the mechanical properties of asphalt mix

3.3.1. Phase I: Conventional asphalt mix

The mechanical properties of asphalt mix prepared with OBC (5.50 %) without the addition of CR:SF is shown in Table 7

Table 7 Mechanical properties of asphalt mix without the addition of CR: SF

Bitumen %(by total weight)	SampleNo.	Stability(Kg)	Flow(mm)	ρA (g/cm3)	Va(%)	VMA (%)	VFB(%)
5.5 %	1	10.70	3.55	2.290	4.9	18.89	74.1
	2	10.10	3.40	2.294	4.8	18.75	74.4
	3	11.84	3.85	2.309	4.2	18.22	76.9
	Average	10.88	3.60	2.298	4.6	18.62	75.3

3.3.2. Phase II: Asphalt mix with CR: SF

According to the procedure previously illustrated in methodology, twenty-one samples were prepared at OBC to evaluate the effect of adding CR: SF to asphalt mixture samples by considering seven proportions of CR: SF (0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1% and

15%:0%) by weight of bitumen. Table 8 shows the mechanical properties of the asphalt mix using different percentages of CR: SF at the OBC.

Table 8 Summary of Mechanical properties of asphalt mix with CR: SF

CR: SF (%)	% SF of bitumen content	% CR of bitumen content	Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
S-1	1%	0%	14.8	3.33	2.335	4.8	17.2	72.1
S-2	0.9%	3%	15.8	3.40	2.342	4.4	17.0	74.1
S-3	0.7%	5%	18.3	3.80	2.671	4.1	16.7	75.7
S-4	0.5%	7%	16.9	3.67	2.361	3.7	16.4	77.1
S-5	0.3%	10%	13.4	3.48	2.652	4.0	5.9	32.7
S-6	0.1%	12%	13.9	3.17	2.592	4.3	8.1	46.2
S-7	0%	15%	14.4	3.37	2.595	4.2	8.1	47.3

3.3.3. Stability Vs CR: SF content relationship

The stability test results are shown in Figure 11. The results show that the stability increases with increasing crumble rubber and decreasing sisal fibers content up to the optimum modifier content and thereafter decreases. The optimum modifier content was found to be S-3.

It can be seen that the stability values for both mixtures met the ERA specification of not less than 9 KN. The results indicate that the asphalt mixture with 0.7% SF & 5% CR has better stability than that of asphalt mixtures without any mixtures. The increase in stability can be attributed to improved adhesion between the aggregate and bitumen.

Generally, the stability of modified asphalt mixes is higher than the conventional asphalt mix (10.88 kg). The maximum stability value is found nearly (18.3 kg) at CR: SF content around **S-3 (0.7% of SF & 5% of CR**). Figure 11 shows the stability of the modified asphalt mix.

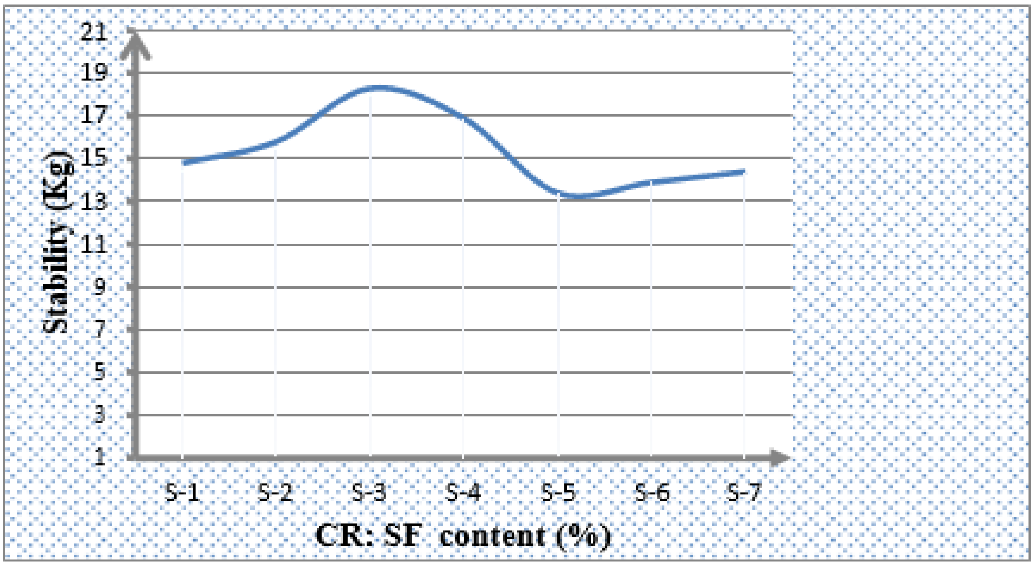

Figure 11 Asphalt mix Stability – CR: SF content relationships

3.3.4. Flow Vs CR-SF content relationship

Marshall Flow measured simultaneously with Marshall Stability, measured the vertical deformation of the samples while loaded. The flow value for the porous asphalt with CR: SF is presented in Figure. 12. The flow value for 0% of CR & 1% of SF content was 3.33 mm. An increase in crumble rubber and decreasing sisal fibers content resulted in an increase in flow up to an optimum value of 0.7% of SF & 5% of CR content (3.8 mm). Further addition of crumble rubber and reduction of sisal fibers content caused the flow to decrease.

Generally, the flow of modified asphalt mix is higher than the conventional asphalt mix (3.6 mm). Figure 12 shows that the flow increases continuously as the percentage of CR increases SF decreases increase then starts to decrease after S-3. The flow value extends from 3.33mm till it reaches 3.8mm at S-3 content (0.7% of SF & 5% of CR).

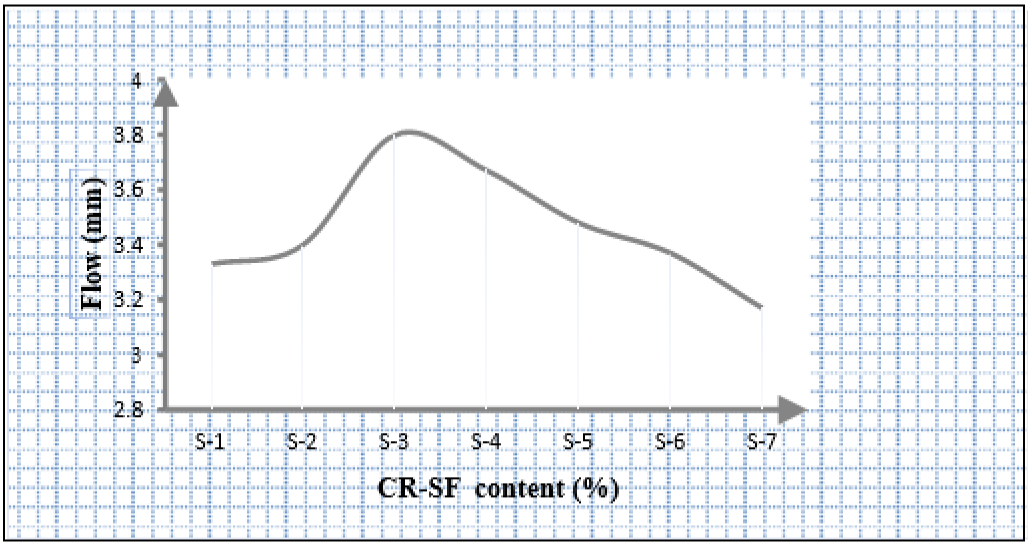

Figure 12 Asphalt mix flow – CR: SF mixes content relationship

3.3.5. Bulk density – CR: SF content relationship

The bulk density of CR: SF modified asphalt mix is higher than the conventional asphalt mix (2.307g/cm3). The general trend shows that the bulk density decreases as the CR: SF content increases. The maximum bulk density is (2.671 g/cm3) at S-3 and the minimum bulk density is (2.335 g/cm3) at S-1. Figure 13 shows the curve that represents the asphalt mix bulk density – CR: SF content relationship.

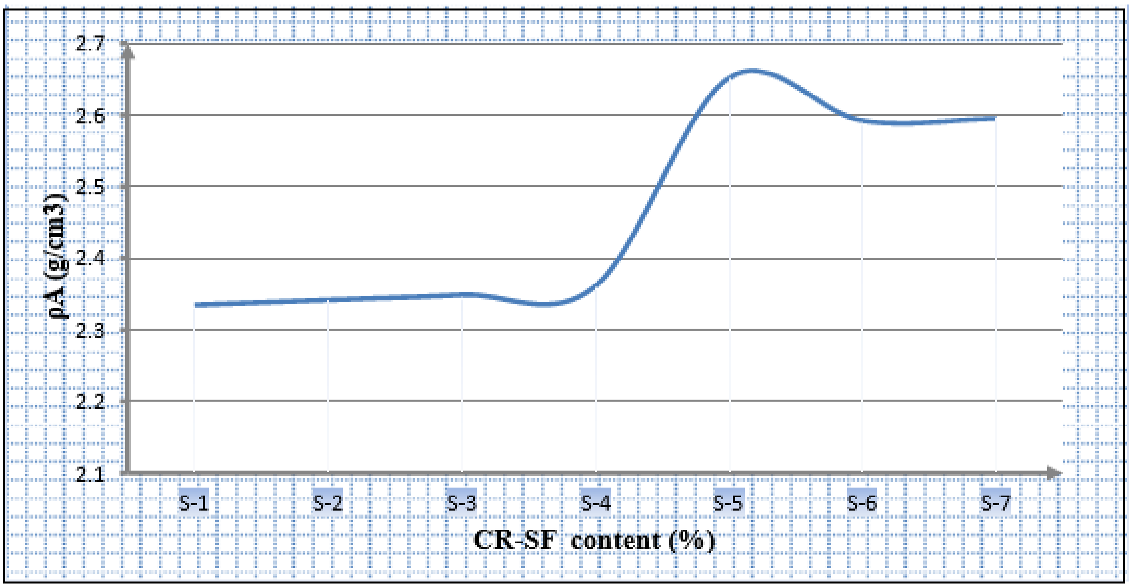

Figure 13 Asphalt mix bulk density – CR: SF relationship

3.3.6. Air voids Vs CR: SF content relationship

In general, the air voids proportion of modified asphalt mixes is lower than conventional asphalt mix (5.1 %). Va % of modified asphalt mixes have a maximum value at S-1. Generally modified asphalt mixes have Va% content within the specifications range. Figure 14 shows the curve that represents asphalt mix air voids – CR: SF content relationship.

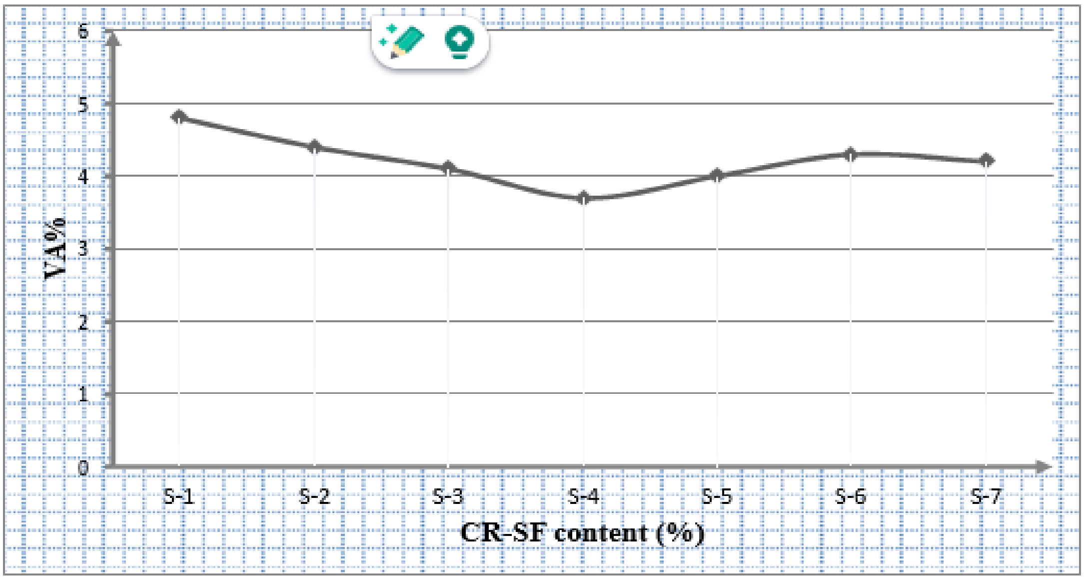

Figure 14 Asphalt mix air voids – CR: SF content relationship

3.3.7. Voids in mineral aggregates Vs CR: SF content relationship

The voids in mineral aggregate percentage for the asphalt mix are affected by air voids in the asphalt mix and voids filled with bitumen. VMA % of modified asphalt mixes decreases as the CR-SF content increase, it reaches (17.2%) at S-1. Figure 15 shows the curve that represents the asphalt mix VMA% – CR: SF content relationship

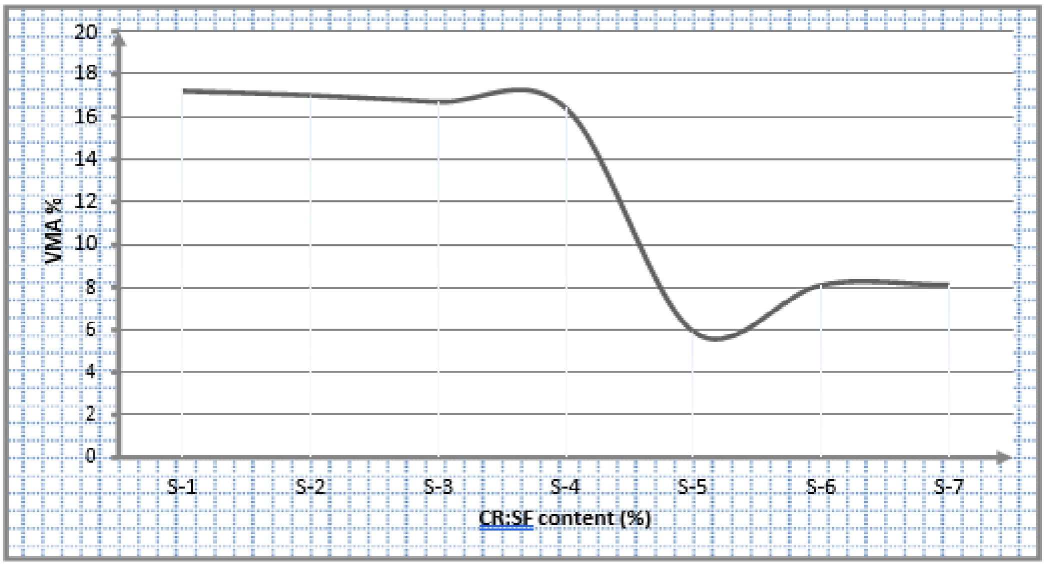

Figure 15 Asphalt mix voids of mineral aggregates – CR: SF content relationship

3.3.8. Optimum modifier content

A set of controls is recommended to obtain the optimum modifier content that produces an asphalt mix with the best mechanical properties (Jendia, 2000). Asphalt mix with optimum modifier content satisfies the Maximum stability, Maximum bulk density & Va % within the allowed range of specifications.

It's clearly shown that asphalt mix modified with (9 % WPB by OBC weight) has higher stability and stiffness compared to the conventional asphalt mix, other properties of the modified mix are still within the allowed range of the specifications. As shown in Figures (5.7, 5..9, and 5.10) it's obvious that modified asphalt mix with 0.7% of SF and 5% of CR by weight of OBC satisfies the requirements of specifications, and Asphalt Institute specifications for all tested properties.

3.3.9. Evaluation of CR: SF modified asphalt mix:

The mechanical properties of CR: SF modified asphalt mix at the optimum CR: SF content with 0.7% of SF and 5% of CR by weight of OBC of bitumen are shown in Table 9.

Table 9 Properties of CR-SF modified asphalt mix with MPWH specification range

Property	Unmodified asphalt mix	Modified asphalt mix
Stability (Kg)	10.88	18.3
Flow (mm)	3.6	3.8
Bulk Specific Gravity (g/cm^3)	2.298	2.349
V_a(%)	4.6	4.1
VFB (%)	75.3	77.1
VMA (%)	16.62	16.7

4. Conclusion

Stability and flow were improved by adding rubber and sisal fibers to the asphalt pavement. The appropriate percentage was 0.7% of SF and 5% of CR by weight of OBC. Standards indicated that the minimum stability of the Marshal Test at heavy traffic (75blows) is 680 Kg. and the maximum flow is 4mm. The 0.7% of SF and 5% of CR by weight of OBC added match with the above standards.

Based on experimental work results for CR: SF modified asphalt mixtures, the Following conclusions can be drawn:

- CR: SF can be conveniently used as a modifier for asphalt mixes for Sustainable Management of plastic waste as well as for improved performance of asphalt mix
- The optimum amount of CR: SF to be added as a modifier of asphalt mix was found to be 0.7% of SF and 5% of CR by weight of OBC.
- Asphalt mix modified with (0.7% of SF and 5% of CR by weight of OBC) has approximately 40% higher stability value compared to the conventional asphalt mix
- Asphalt mix modified with CR-SF exhibits higher flow value when the Crumb Rubber percentage increased and SF decreased. However, the stiffness of the modified mix decreased.
- All test values are consistent with the limits of the specifications.
- The results of this study apply only to the type of rubber and fibers that were used. Other sources of rubber and fibers may produce different results.

Recommendation

- The study recommends local authorities to confirm using CR-SF in asphalt mix with the proposed percentage (0.7% of SF and 5% of CR by weight of OBC) for improved performance of asphalt mix.
- Further studies are needed on various topics related to effective utilization and best incorporation techniques of waste materials in asphalt pavements.
- It is recommended to conduct similar studies on the wearing course layer of asphalt pavement.
- Government and researchers should integrate efforts toward preparing and implementing a sustainable solid waste management plan taking into consideration getting the maximum benefit from the high quantities of solid waste

Compliance with ethical standards

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Disclosure of Conflict of Interest

All authors declare that they have no conflicts of interest.

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