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EFFECT OF INCORPORATING RAM-FAT AND OIL INTO THE BITUMEN GRADE 60/70

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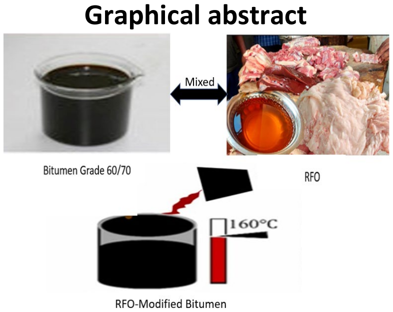
Graphical abstract



Abstract

The ability of a pavement to resist fatigue cracking, rutting, and thermal cracking is mostly dependent on bitumen, which assists in minimizing the occurrence of pavement distress. The objective of the study is to determine the optimum ram fat and oil (RFO) content suitable for the application of bituminous mixtures. Saturated fats and oils consumption in excess can boost blood levels and may lead to bad low-density lipoproteins cholesterol, which raises the danger of heart failure and stroke. To minimize this problem, this study encourages the incorporation of RFO into bitumen to reduce the consumption of fats and oils in our society. The characteristics of the standard and RFO-modified binders were evaluated by penetration, softening point, and ductility tests. The RFO content (1.0%, 2.0%, 3.0%, 4.0%, and 5.0% by mass of the bitumen) was blended with the bitumen for 35 minutes with a mixing speed of 1000 rpm. The result of the optimum RFO content was discovered at 3.0% which improved the performance of the mixture. It was found that bitumen grade 60/70 documented a significant improvement with the addition of RFO content. The optimum RFO content can be raised with a smaller bitumen grade.

Keywords: Ram, fat, oil, bitumen grade 60/70, construction materials.

1.0 INTRODUCTION

The ability of a pavement to resist fatigue cracking, rutting, and thermal cracking is mostly dependent on bitumen, which assists in minimizing the occurrence of pavement distress. The main causes of pavement distress are often heavy-weight traffic and seasonal variations, which affect the pavement's behaviour and stability [1]. The majority of pavement distresses are bitumen-dependent [1]. Bitumen modification is progressively expanding the pavement sector globally [2]. To obtain improved binder characteristics, a specific modification is needed to initiate a chemical response with the binder molecule or to generate new or secondary synchronization in bitumen. It must improve as compared to standard bitumen to preserve pavement behaviour. Numerous attempts are being made to modify bitumen through physical or chemical modification.

According to Atojunere [3], different places of the world have different amounts of bitumen, including Trinidad & Tobago, Venezuela, and Canada. The manufacture, construction, and functionality of bituminous pavements are aided using viable and replacement binder materials in the road construction industry. When a reserve product is economically, ecologically, and technically feasible, it is deemed justifiable. Technically speaking, this product should work with road construction materials and be useful with paving devices and current construction. A product that is reasonably justifiable and readily accessible is appropriate for the discovery's intended use and rationally adds importance. There shouldn't be any detrimental effects on the viability of the ecosystem. Currently, a few replacement binders such as Escherichia Coli [4], vegetable oil waste [5], agro-industrial left-over[6], cement, and lime [7], brewers [8], palm kernel shell [9], Portland cement [10], and waste-animal fats [11] has already been used globally in bitumen modification. These replacement binders need to be chemically modified to increase their viscosity. According to Srinivasan [11], in terms of economics and productivity, the fats had demonstrated to be a competitive feedstock than waste-cooking and vegetable oils. RFO would therefore be a useful replacement binder.

Lipids that are generated from dense fats and unsolidified oils at ambient temperature are known as RFOs. Triglycerides make up the chemical structure of both oils and fats [12][13]. Bitumen-like characteristics are shared by lipid constituents, and asphalt's ability to adhesive is attributed to the bitumen's polar workability classifications. The chemical compositions of the binder can be categorized as bio-oils [14], resins [15], and bitumen [16], or as a blend of polar and non-polar particles [17]. The oil-based particles are responsible for the flow properties. Fats and oil may be derived from different parts of the ram, but in practical usage, reduced tissue fats and oils from cattle including cows, chickens, and pigs are the main source of fats and oils [11][18]. Demirbas [18] reported that vegetal oils and fats may be converted into diesel-based fuel in four various methods: (i) pyrolysis (thermal cracking), (ii) mixing, dilution with hydrocarbons, (iii) transesterification, and (iv) emulsification.

The transesterification of vegetal oils and animal-based fats is the most often utilized method [18][19]. The transesterification response is influenced by various factors such as the moisture content of fats and oils, catalysts, temperature and duration of the response, and the molecular proportion of glycerides to alcohol [18][20][21]. Moisture and free fatty acids (FFA) usually have a detrimental effect on transesterification because they consume catalysts, contribute to the production of soap, and decrease catalyst efficacy, all of which lower conversion [18][21][22]. Therefore, RFO is anticipated to be able to be utilized as a rejuvenator in road construction materials because the FFA of RFO and its hydrocarbon particles are comparable [23][24][25]. According to Ruth [26], the identification of one or more product-specific makers is necessary for the sorting of fat and oil.

The objective of the study is to determine the optimum RFO content suitable for the application of bituminous mixtures. The application of 3.0% RFO for future mix design is the main contribution of the study. The study also contributes to comprehending the effect and performance of RFO on the modified bitumen for potential application in road construction industries. The validation of the laboratory assessment of RFO is a challenging task that typically calls for bitumen to be modified. It also involves consideration of the bitumen and RFO contents during the validation assessment. Saturated fats and oils consumption in excess can boost blood levels and may lead to bad low-density lipoproteins cholesterol, which raises the danger of heart failure and stroke. To minimize these problems, this study encourages the incorporation of RFO into bitumen grade 60/70 to reduce the consumption of fats and oils in our society.

2.0 MATERIALS AND METHODS

Three phases comprised the methodology holistic approach (Figure 1). The background information needed to support the research's objective took up the majority of the first phase. The materials (bitumen grade 60/70, RFO, and aggregates), previous results of the scanning electron microscopy (SEM), and preparation of the samples comprised the second phase. The laboratory tests such as penetration, softening point, and ductility tests were the main emphasis of the third phase. After analyzing and interpreting the laboratory test outcomes, a logical conclusion was reached.

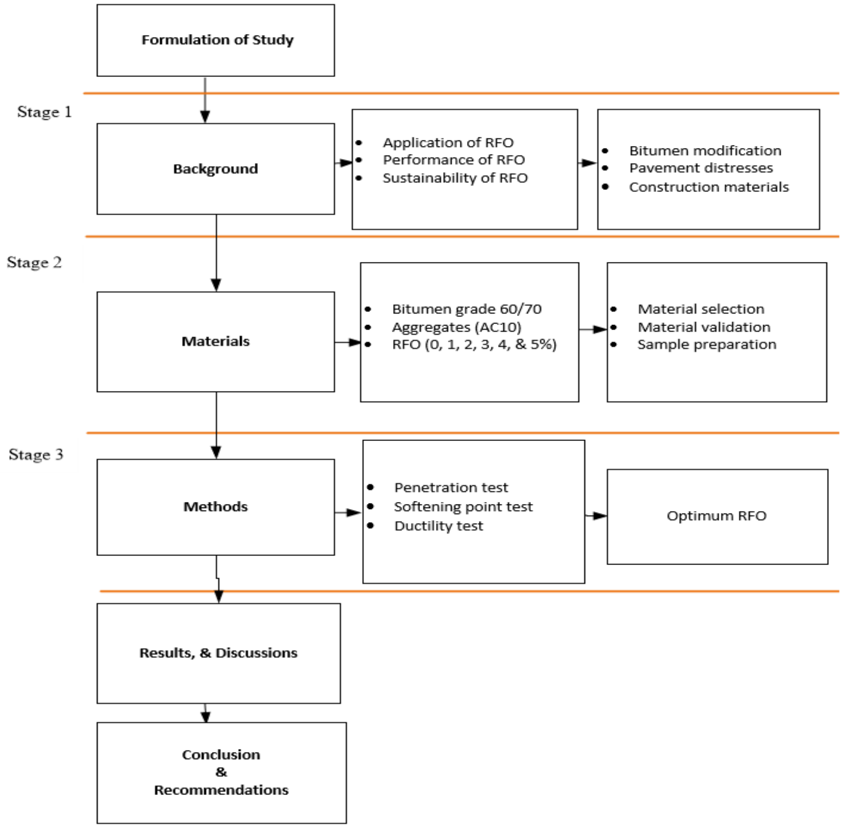


Figure 1 Methodology holistic approach

2.1 Materials

Bitumen grade 60/70 was provided by the Faculty of Civil Engineering (FKA), Universiti Teknologi Malaysia (UTM), Skudai, Johor Bahru. A total amount of 1500 g of bitumen grade 60/70 was utilized in each test. The bitumen grade 60/70 was kept at room temperature in an air-protected atmosphere. According to JKR (2008) and [2], the optimum bitumen content (OBC) for the modified and standard bitumen samples, which ranged from 5.5% to 7.5% and 5% to 7%, respectively, are appropriate for the Marshall mix design. Some designated characteristics of this bitumen are presented in Table 1.

The RFO was collected from Taman Sri Pulai Perdana, Johor Bahru, Malaysia. Once the ram has been slaughtered, fat is removed from its meat. To remove the suspended elements from the fat oil, the fat was placed in the oven at a standard temperature until it liquefied and then filtered using filter paper. The RFO contents of 1.0%, 2.0%, 3.0%, 4.0%, and 5.0%, were selected in this study. Applying the low volume of RFO contents into bitumen grade 60/70 was the rationale behind the selection of the contents.

Following JKR (2008), coarse, fine, and filler aggregates were used. The aggregates used in this research were provided by the FKA, UTM, Johor Bahru, Malaysia. The aggregates were limited to a maximum size of 10 mm and their gradation limits were presented in Table 2. The particle size distribution was used to evaluate the gradation limits of aggregates. Figure 2 shows the materials used in this study.

The filter paper with a diameter of 12.5 cm was employed based on ASTM D4124 standard. The chemical characteristics of the gas chromatography-mass spectrometry (GCMS) were used to assess RFOs in the progressive mass-spectrometry laboratory. The results of the physical and chemical characteristics of RFO are provided in Tables 3 and 4, respectively.

Table 1 Characteristics of the bitumen grade 60/70

S/N	Characteristic	Unit	ASTM Standard	ASTM Method
1	Penetration	0.1 mm	60 – 70	D5
2	Softening point	^{0}C	48 – 56	D36
3	Storage stability	^{0}C	<2.20	D7173
4	Solubility	Wt. %	99.50	D2042
5	Ductility @ 25 ^{0}C	cm	≥100.00	D113
6	Flash and fire point	^{0}C	230 (min)	D92
7	Loss on heating	Wt. %	0.20	D6
8	Decrease in penetration after heating	Wt. %	20.00	D5
9	Relative density	g/cm^3	1.00 – 1.06	D70
10	Viscosity	Pa.s	≤3.00	D4402
11	Dynamic shear rheometer	kPa	>1.00	D7175

Table 2 Aggregate (10 mm) gradation JKR (2008)

BS sieve size (mm)	Gradation limits	Percentage mean (%)	Percentage passing (%)
14.0	100	100	-
10.0	90 – 100	95	5
5.0	58 – 72	65	30
3.35	48 – 64	56	9
1.18	22 – 40	31	25
0.425	12 – 26	19	12
0.150	6 – 14	10	9
0.075	4 – 8	6	4

Table 3 Physical characteristics of RFO

S/N	Characteristic	Unit	RFO Standard
1	Food energy per 100 g	kJ	3770
2	Melting point	^{0}C	-
	Back fat		30 – 40
	Leaf fat		43 – 48
	Combined fat		36 - 45
3	Smoke point	^{0}C	121 - 218
4	Specific gravity @ 20 ^{0}C	-	0.917 – 0.938
5	Saponification value	-	190 - 205
6	Non-saponification	%	0.8
7	Iodine value	-	45 – 75
8	Acid value	-	3.4

Table 4 Chemical characteristics of RFO

S/N	Type of FFA	RFO (%)
1	Oleic	47.82
2	Palmitic	27.35
3	Palmitoleic	10.78
4	Stearic	6.82
5	Myristic	3.27
6	Linoleic	2.22
7	Others	1.74
	Total	**100.00**

Figure 2 Materials

2.1.1 Results of the SEM

Utilizing an attentive electron beam, SEM produces images with a significantly higher resolution than visual microscopy by scanning a sample's surface [28]. This device can have resolutions of numerous nanometres to less than one nanometre [28]. According to Akyuz et al [28], the effect of integrating fats and oils into chitosan on its SEMs (Figure 3) is a consistent and uniform process.

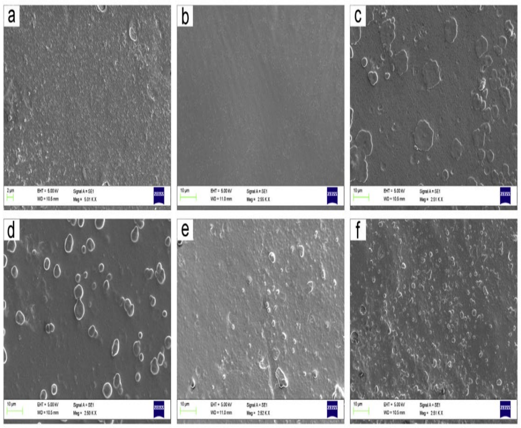


Figure 3 SEMs of the: (a). a mixture of chitosan-virgin, (b). a mixture of chitosan-olive oil, (c). a mixture of chitosan-corn oil, (d). a mixture of chitosan-sunflower oil, (e). a mixture of chitosan-butter, and (f). a mixture of chitosan-animal fat [28]

2.1.2 Preparation of Samples

Initially, the bitumen grade 60/70 was heated after being weighed on a weighing balance. After measuring and gradually adding the required amount of RFO, 1.0% by weight of binder was replaced. One can maximize performance improvements by achieving the ideal mixture properties from RFO modification by imposing advanced load and strain conditions on the system. As a result, the binder and RFO were combined and heated to 165 ^{0}C for 35 minutes at a mixing speed of 1000 rpm. Using a rotating viscometer, the binder's viscosity was measured at two different temperatures: 135 ^{0}C was 0.520 cP, and 165 ^{0}C was 0.192 cP (Figure 4). Based on the viscosity-temperature curve, the mixing and compaction temperatures were calculated, and it was equivalent to 0.17±0.02 poises (Asphalt Institute, 2007). The rejuvenating specimens were placed in penetration cups, which were labelled and kept separate for the testing of softening points and penetration specimens. The number of samples prepared for the control sample was four for each test conducted. For the RFO-modified sample, the number of samples prepared was four for each content (that is twenty samples for each test conducted).

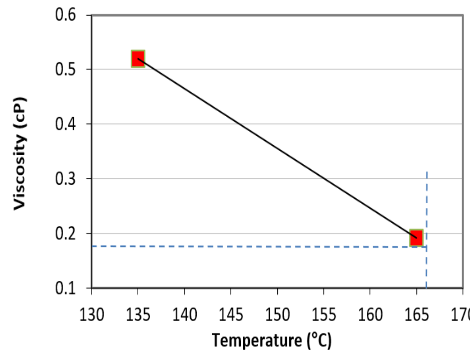


Figure 4 Mixing and compaction temperatures for bitumen grade 60/70

2.2 Methods

The three laboratory tests conducted were (i) penetration test, (ii) softening point test, and (iii) ductility test. The production temperature for all the specimens was 160 ^{0}C. The tests were discussed in the subheadings.

2.2.1 Penetration Test

This test aimed to evaluate the binder's homogeneity by penetrating it perpendicularly downward for 5 seconds at 25 ^{0}C with an indicator force of 100 g [29]. Penetrometers, cylindrical measurements, needles, and other tools were used in conducting this test. RFO-modified samples were made by mixing the binder with RFO contents for 35 minutes with a mixing speed of 1000 rpm. The sample was heated and then put into the cylinder-shaped measure. The normal thermometer had its reading set to zero before the test. The needle was placed and verified to ensure it touched the sample's surface, as shown in Figure 5. The penetration button was pressed, allowing the needle 5 seconds to enter the sample. A reading of the penetration in mm was recorded. After completing the procedure 3 times, the mean penetration was noted for every sample. The test met the conditions outlined in the ASTM D5 specifications.

Figure 5 Penetration test

2.2.2 Softening Point Test

This test aimed to find the temperature at which the binder changes (a solid to a liquid state). Using a glass beaker, a 9.5 mm steel ball, a stirrer instrument, a wristwatch, a numerical thermometer, a brass ring mould, a ball and ring system, ball guides, and forceps, this test was carried out per ASTM D36 specifications. RFO was mixed with a binder for 35 minutes with a mixing speed of 1000 rpm to make an RFO-modified specimen. After being placed in a container, the specimen was heated to 100 0C [30]. The RFO-modified sample was loaded into the rings after positioning. 30 minutes were spent letting it cool at ambient temperature. After air-conditioning, a hot, pointed pallet knife was used to level the sample inside the ring and remove any excess material. The ring and ball system was put together, and then the bath was filled with warm water until it reached a height of 50 mm over the top of the rings. The water was then stable for fifteen minutes at an ambient temperature. Then, with the use of forceps, a ball was placed into every single ball cantering guide. Figure 6 illustrates how the RFO-modified sample was agitated, and the bath heated up until a complete fluid was forced into a metal ring mould. The mean of the three recorded temperatures for every sample was used to calculate the softening point of the bitumen.

Figure 6 Softening point test

2.2.3 *Ductility Test*

This test frequently yields information about its ductile and grade strengths. The binder's level of elasticity was assessed during the application of gentle stress. A brass plate, mould, spatula, water bath, and other testing tools were used to conduct the test per ASTM D113 criteria. For 35 mins with a mixing speed of 1000 rpm, the binder was mixed with the contents of RFO to make an RFO-modified sample. Before the sample was put into the mould, it was gradually agitated. The RFO-modified sample was allowed to cool in the mould before being submerged in a water bath to keep the temperature at 25 ^{0}C for a minimum of one hour. A spatula was used to trim the extra sample inside the mould. Therefore, the average of the three samples was noted and reported as a sample ductility. The ductility samples are provided in Figure 7.

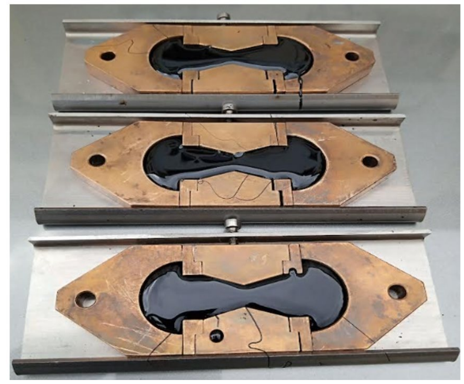


Figure 7 Ductility samples

3.0 RESULTS AND DISCUSSIONS

Penetration can specify the degree of uniformity and softness of bitumen. The addition of RFO content (0.0%, 1.0%, 2.0%, 3.0%, 4.0%, and 5.0%) by bitumen mass was mixed thoroughly. The effect of penetration with the addition of RFO and the Standard Deviation (SD) ranges between 0.00 mm and 1.39 mm (Figure 8). The penetration of the control sample (standard bitumen at 0.0%) has a lower penetration value (65.5 mm) than RFO-modified samples. The penetration increases with the increased RFO content into bitumen, until 4.0% where a decrease was observed up to 5.0%. This implies that adding RFO content can soften bitumen by decreasing its consistency. The maximum penetration (69.5 mm) was detected at 3.0% RFO corresponding to 97% bitumen content. Therefore, this result (69.5 mm) has met the JKR (2008) standard. At 3.0% RFO, the modified bitumen becomes softer compared to other RFO contents. At this point, the reported optimum RFO content is 3.0%, which has a promising effect on the characteristics of bitumen grade 60/70.

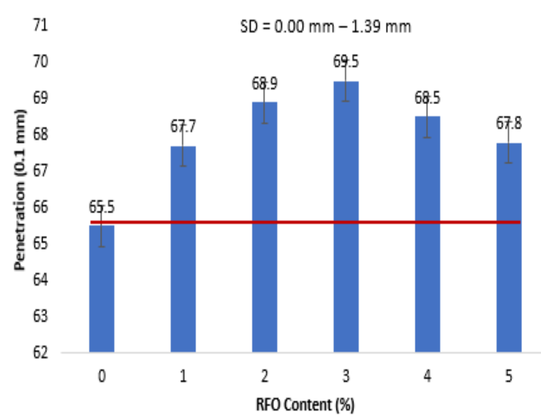


Figure 8 Effect of penetration and RFO content

The softening point (47.9 ^{0}C) of the standard sample at 0.0% was lowered compared to RFO-modified samples. The softening point (Figure 9) increases with the addition of RFO content into bitumen. At 3.0%, a maximum softening point of 51.7 ^{0}C was noted followed by a decrease from 4.0% to 5.0% RFO. Therefore, there is a significant improvement in the temperature after the addition of 3.0% RFO content. This implies that at 3.0%, an optimum RFO content is also achieved corresponding to 97% bitumen content. Both the standard and modified samples have met the JKR (2008) standard. Therefore, the reported optimum RFO content is 3.0%, which has a significant effect on the characteristics of bitumen grade 60/70. The softening point's SD varies from 0.00 C to 1.53 C.

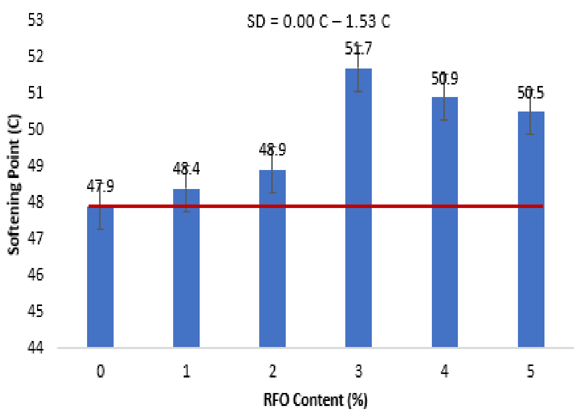


Figure 9 Effect of softening point and RFO content

The RFO-modified samples recorded higher ductility compared to standard bitumen. The reported overall optimum RFO content is 3% corresponding to 97% bitumen content. The effect of ductility with the addition of RFO is depicted in Figure 10. The ductility of the standard bitumen at 0.0% (109 cm) has a lower ductile strength compared to RFO-modified samples. The ductile strength increases with the increased RFO content in bitumen, until at 4.0% and 5.0% where a decrease was detected. This indicates that the addition of RFO content can increase the ductile strength of the bitumen grade 60/70. The maximum ductility (115 cm) was observed at 3.0% RFO corresponding to 97% bitumen content. Therefore, there is an improvement in the ductile strength after the inclusion of 3.0% RFO content. The results of the ductility test have met the JKR (2008) standard. At this point, the overall optimum RFO content is also 3.0%. The ductility's SD ranges between 0.00 cm and 2.16 cm.

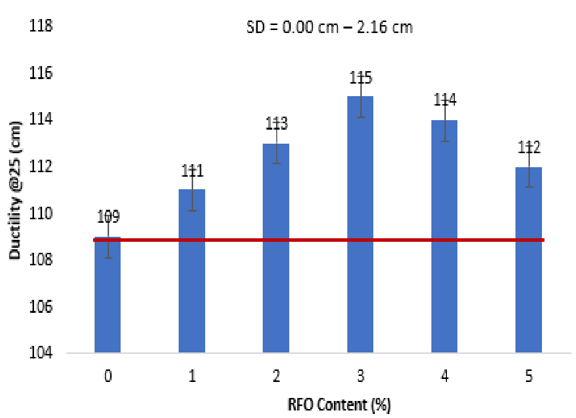


Figure 10 Effect of ductility and RFO content

Furthermore, gap analysis of the three tests was carried out with the comparison of results and the test methods according to ASTM specifications. A gap variation was detected between the three experiments as shown in Figure 11. All the results and standard methods of the three experiments have conformed with the ASTM standards.

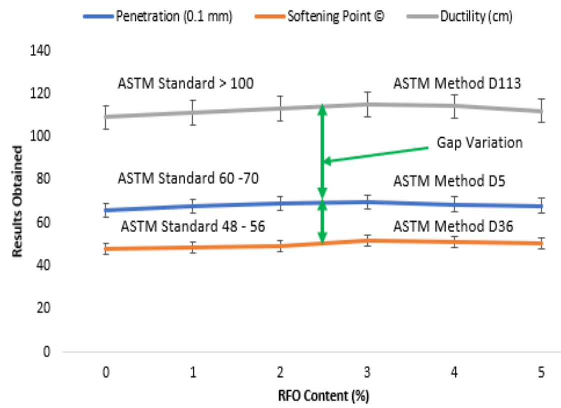


Figure 11 Gap variation of the three experiments

4.0 CONCLUSION

The objective of the study was to determine the optimum RFO content suitable for the application of bituminous mixtures. This study contributes to comprehending the effect and performance of RFO on the modified bitumen for potential application in road construction industries. In this study, RFO is a promising and sustainable modifier. The penetration, softening point, and ductility tests were conducted to assess the effect of incorporating RFO in various characteristics of bitumen grade 60/70. The results of these tests are concluded as follows:

- It was found that the RFO under study has improved the characteristic (an optimum penetration of 69.5 mm at 3.0% RFO) of bitumen grade 60/70.
- The softening point has recorded a significant improvement (51.7 ^{0}C) in the temperature after the addition of 3.0% RFO compared to other RFO contents.
- An optimum ductile strength of 115 cm was achieved at 3.0% RFO corresponding to 97% bitumen content. This suggests that bitumen grade 60/70 modified with 3% RFO will produce a sustainable sample that will add value to pavement design life.
- There was a gap variation between the three binder tests conducted in this study. Their results were compared with the ASTM standard and were found appropriate for mix design.
- The application of 3.0% RFO for future mix design is the main contribution of the study.
- Further studies on high-volume RFO are needed to validate its structural performance.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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