

1 Research Paper

2 Effect of Adding Different Sizes of Carbon Fiber on the Proper- 3 ties of Asphalt Mix

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15 Abstract

16 This study investigates the impact of carbon fibers of varying sizes on asphalt mixtures,
17 focusing on improving mechanical properties and durability using the dry mix process.
18 The bitumen grade 60/70 was used, and three fiber sizes; fine, medium, and large were
19 tested at 0.1% to 0.5% by weight. And key performance parameters, including stability,
20 flow, bulk density (Gmb), air voids (Pa), voids in mineral aggregate (VMA), and voids
21 filled with bitumen (VFB), were measured. Results showed that fiber size and percentage
22 significantly affected performance, with optimum results at 0.3% for fine fibers, 0.4% for
23 medium fibers, and 0.5% for large fibers. Stability increased due to better micro-reinforce-
24 ment, while flow, Gmb, VMA, and VFB values improved with higher fiber content. The
25 study concludes that carbon fibers enhance asphalt mix performance, with fiber size and
26 content optimized for specific needs, suggesting further exploration of hybrid fiber com-
27 binations for sustainable road construction.

28 **Keywords:** Carbon fibers, CFF, CFM, CFL, OBC, Asphalt mix, Marshall Stability, Flow
29 Value.

30 1. Introduction

31 Asphalt mix, despite its wide application in civil engineering works, is considered
32 more problematic than other construction materials due to its limited durability and me-
33 chanical weaknesses. Issues such as low tensile strength, susceptibility to cracking, and
34 deformation under repeated loads have pushed researchers to explore modification meth-
35 ods to enhance its performance. Various additives have been investigated, including pol-
36 ymers and fibers, which are among the most effective modifiers. However, fibers have
37 gained particular importance because of their reinforcement potential and their ability to
38 improve the long-term serviceability of asphalt pavements [1]. Fiber-reinforced asphalt
39 concrete (FRAC) has been the subject of extensive research, and results highlight the val-

uable role of fibers in pavement engineering. Fibers increase cohesion within the mix, mitigate reflective and fatigue cracking, and strengthen resistance against permanent deformation, thereby enhancing the overall durability of the material [2]. Moreover, fibers also function as stabilizing agents, reducing binder drain-down in mixes with high asphalt binder contents, such as porous asphalt and Stone Matrix Asphalts (SMAs). This dual role of reinforcement and stabilization makes fibers highly versatile. Therefore, incorporating fibers into asphalt mixtures is a practical approach to overcome inherent deficiencies, leading to pavements that are stronger, more resilient, and sustainable in the long run [3]. The research aim is to investigate the properties of asphalt mix by using partial replacement of different aggregate sizes with carbon fibers and objectives of this research are; to investigate the effect on the mechanical properties of hot mix asphalt by varying different sizes and percentage of carbon fiber in the mix and to optimize the carbon fiber content in the mix comparing properties of conventional and modified Asphalt mix. The research addresses the possibility of integrating carbon fiber into the design of asphalt mix to improve the pavement performance and durability. The paper provides important insights on how the fibers could be incorporated into actual practice to develop advanced and environmentally friendly pavements through its analysis of the unique mechanical and electrically conductive qualities of the fibers. At the same time, it also promotes cost-efficient construction practices with the aim of maximizing the service life of a pavement and reducing the amount of maintenance at the same time, which promotes sustainable development of infrastructures.

2. Literature Review

Permeable pavement systems, mainly used in light-traffic areas, face strength limits. Research on new binders and additives like nano silica, rubber, fibers, and eco-compounds shows potential for enhanced performance and durability [4]. The study tested hot-mix asphalt with treated RCA and carbon fibers, finding improved Marshall stability and dynamic stability, where carbon fibers offset RCA's rutting drawbacks, enhancing mixture performance significantly [5]. The study on HMA with RCA and carbon fibers showed all mixes met Iraqi standards, with higher asphalt content and carbon fibers notably boosting stability, especially at 60% RCA with 0.35% [6]. Fibers in asphalt pavements improve stability and strength, with effectiveness influenced by size, dosage, and mixing. Combined with additives and recycled fibers, they enhance sustainability while maximizing environmental and performance benefits [7]. Open-graded asphalt with carbon fibers improved Marshall stability, abrasion resistance, and moisture sensitivity, while reducing drain-down. Despite minor decreases in permeability and air voids, overall mixture performance was significantly enhanced [8]. The study explored shredded cigarette butts as fiber substitutes in SMAs, finding them viable for enhancing stability and mechanical properties, offering an eco-friendly alternative to cellulose fibers while promoting circular economy goals [9]. The study developed conductive asphalt by replacing natural aggregates with carbon fibers (0.2–0.4%) and iron tailings. Results showed optimized electromechanical performance, improved strength, reversible resistance changes under load, and enhanced durability, with 0.4% CF + TA mix providing the best balance of conductivity, resilience, and long-term application potential [10]. The study found carbon fiber addition (0.3–0.7% of bitumen weight) greatly enhanced asphalt performance, boosting shear stress resistance, fatigue life, deformation resistance, stiffness, and moisture resistance, ultimately improving durability, cohesion, and overall pavement performance significantly compared to conventional mixtures [11]. The study showed carbon fibers improved Marshall resistance and flow in asphalt mixes, with 1.5% fiber increasing resistance by 32%. However, 3% reduced resistance but boosted flow 189%. High fiber costs demand selective, tactical application [12]. The study tested fiberglass, basalt, carbon, and polyolefin/aramid fibers in HMA, finding fiber reinforcement improved volumetric properties, durability, and rutting

resistance. Mixing method influenced uniformity, with overall results confirming fibers significantly enhanced performance and extended asphalt pavement service life [13].

Table.01nstructured literature review in a table format for better clarity:

3. Novelty of Research

While extensive research has explored the role of carbon fibers in improving the mechanical and volumetric characteristics of asphalt mixtures, limited attention has been paid to fiber size as a critical influencing factor. The proposed study aims to address this gap by systematically investigating how different carbon fiber dimensions affect mixture performance. Emphasis will be placed on identifying the most suitable fiber size to optimize durability, rutting resistance, and workability. The expected outcome is to provide practical recommendations for designing fiber-reinforced asphalt mixtures that can perform effectively under varying traffic demands and environmental conditions.

4. Research Methodology

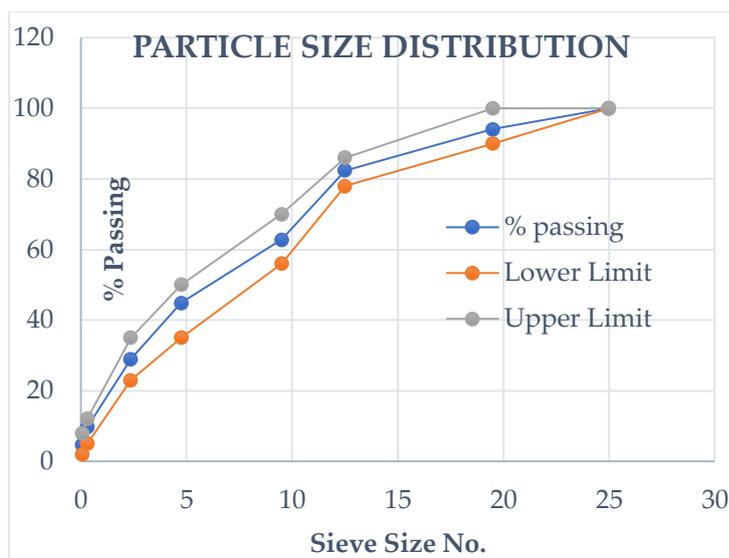
The materials and methodology used in the preparation of both conventional and modified asphalt specimens are outlined below:

4.1 Aggregates

In this research, local aggregates from kotbungalow, Khairpur Mir’s, Sindh, Pakistan were used. The aggregate gradation was selected according to the wearing course Class B (specifications provided by NHA, Pakistan) and blending of aggregates adopted as per Combined Aggregate Grading Requirements as per ASTM D 3515. The following table 1 and graph 1 show the blending of aggregates and combined specific gravities of aggregates respectively.

Material	Total Blend	Target Value	Specification
25mm	100	100	100
19.5mm	94.05	95	90-100
12.5mm	82.41	82	78-86
9.5mm	62.76	63	56-70
4.75mm	44.89	42.5	35-50
2.36mm	28.91	29	23-35
300µm	9.64	8.5	5-12
0.075µm	4.70	5	2-8

Table1: Agg. Blending for Asphalt Mix Design



Graph 1: Percentage Passing Vs Sieve Size No.

4.2 Bitumen

Bitumen with 60/70 grade was used in the making of asphalt mixture for all the specimens.

4.3 Carbon Fibers

The carbon fibers utilized in this study were sourced from Matrix Company, Karachi. They were categorized by length (6–12 mm) and diameter into three groups: fine fibers (passing sieve #50 and retained on #200), medium fibers (passing sieve #8 and retained on #50), and large fibers (passing sieve #4 and retained on #8), referred to as CFF, CFM, and CFL, respectively. Each fiber category was incorporated into the mixtures using the dry process at replacement levels ranging from 0.1% to 0.5% by the weight of the corresponding aggregate fraction.

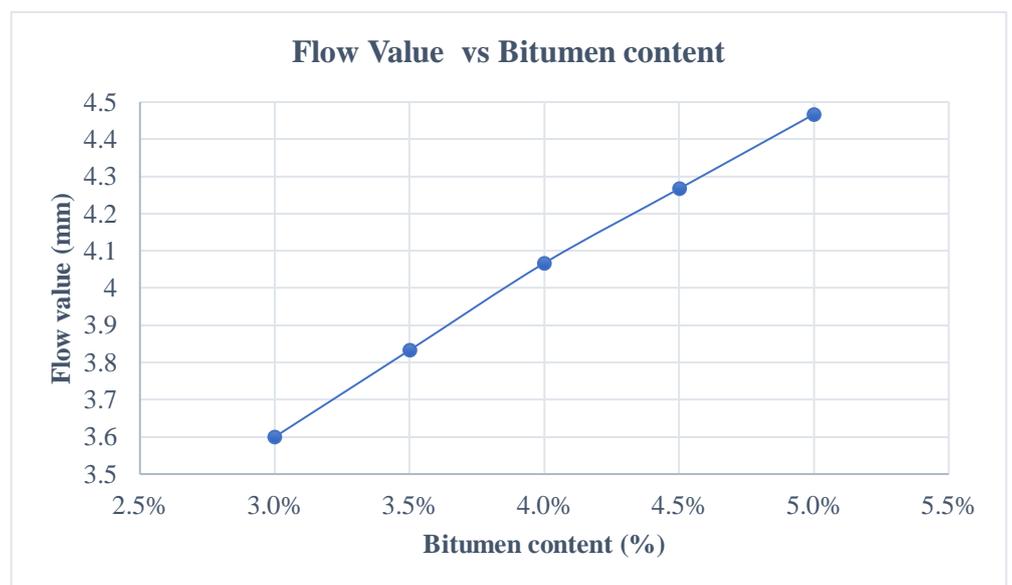
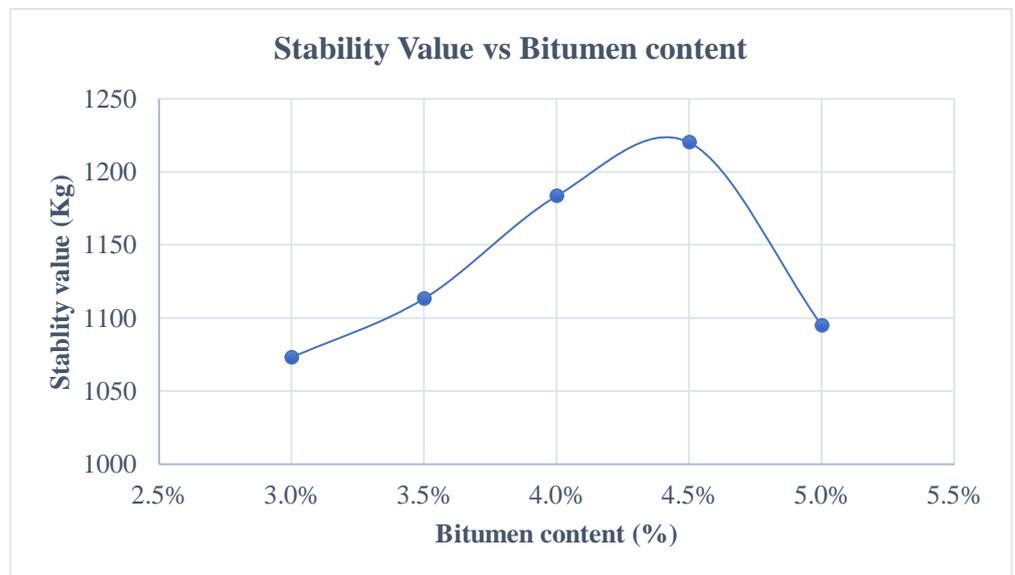
4.4 Sample Preparation

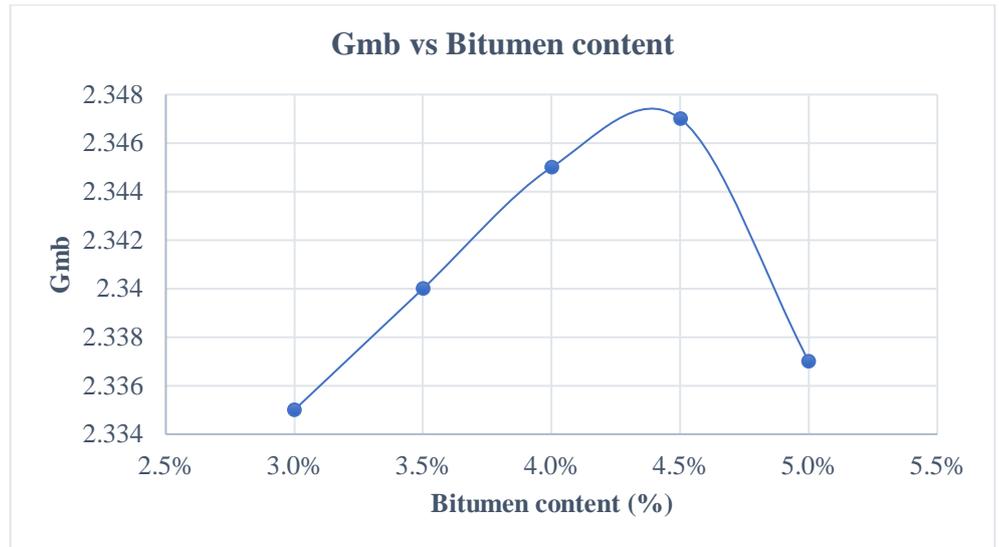
The experimental methodology commenced with determining the Optimum Bitumen Content (OBC) using the Marshall mix design approach, where trial specimens were prepared with bitumen contents varying between 3% and 5% at 0.5% increments. The OBC was calculated as the mean value corresponding to stability, unit weight (Gmb), and air voids (Pa). Aggregates, proportioned according to the specified gradation, were oven-dried at 175–190 °C and subsequently mixed with bitumen heated to 121–125 °C at a blending temperature of 150–160 °C. The mixtures were molded into standard Marshall specimens (63.5 mm height, 101.6 mm diameter), compacted with 75 blows on each face using a 4.5 kg hammer, and cured for 24 hours. Marshall stability and flow tests were conducted on conventional asphalt mixtures (without fibers) for baseline comparison. For the modified mixtures, selected aggregate fractions (passing through sieve #50, #8, and #4) were replaced with carbon fibers (CFF, CFM, CFL) at proportions of 0.1–0.5%. The fibers were pre-coated onto hot aggregates at 160 °C before adding 60/70 grade bitumen, ensuring uniform dispersion. Finally, the modified mixtures were compacted under identical conditions to produce test specimens for performance evaluation.

5. Results

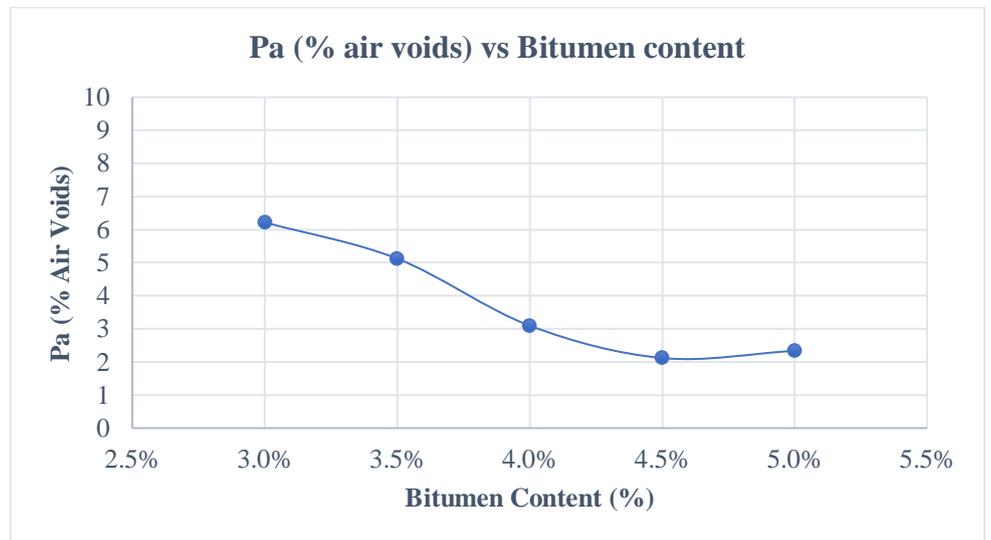
5.1 Optimum Bitumen Content (OBC) Results

Bi- tu- men (%)	Sta- bil- ity (Kg)	Flow (mm)	Gmb	Pa (%)	VFB (%)	VMA (%)
3	1073.065	3.6	2.335	6.218	45.561	11.422
3.5	1113.354	3.833	2.34	5.122	55.503	11.511
4	1183.543	4.067	2.345	3.096	71.235	10.763
4.5	1220.147	4.267	2.347	2.119	80.689	10.973
5	1094.992	4.467	2.337	2.336	80.965	12.272

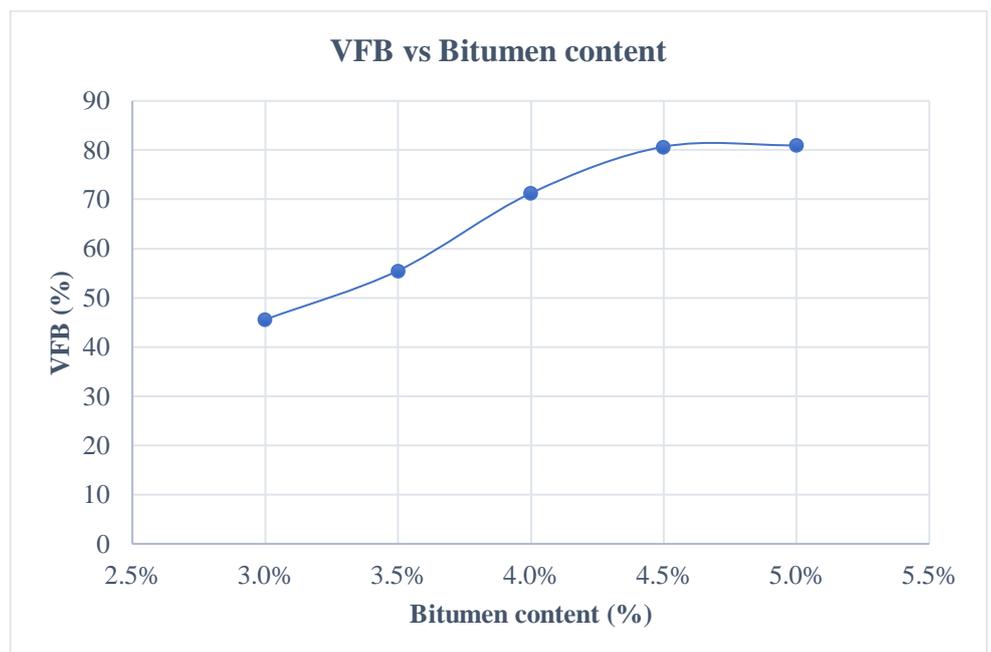




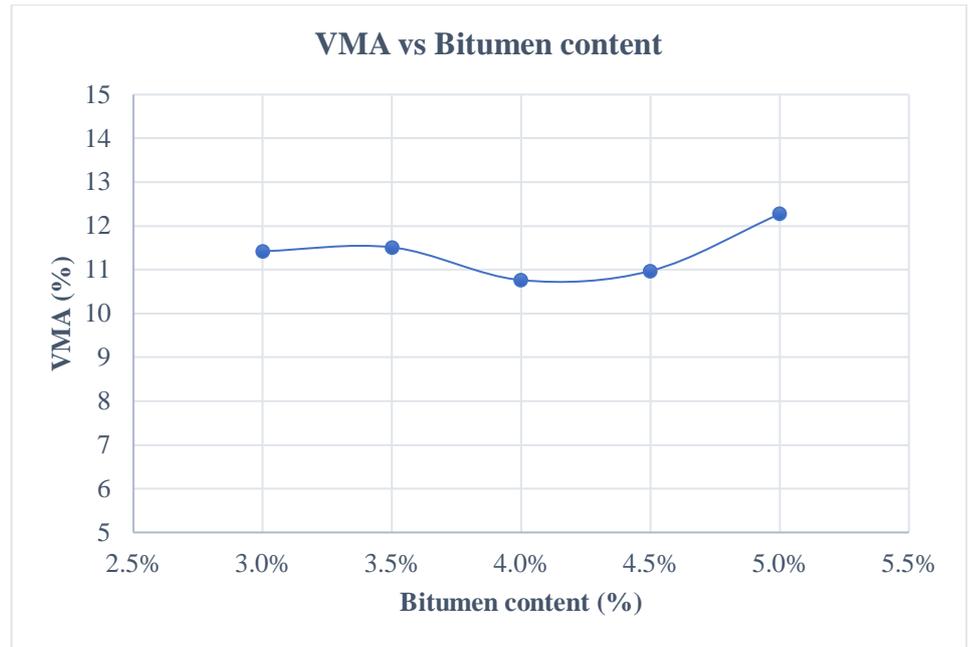
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Optimum Bitumen Content:

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Bit.i= Bitumen conten.t at maximum stability = 4.4%

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Bit.ii= Bitumen conten.t at maximum 4% Air voids = 3.8%

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Bit. iii= Bitumen conten.t at maximum specific gravity = 4.4%

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O.B.C = (B.1+B.2+B.3)/3

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Optimum Bitumen Content = 4.19%

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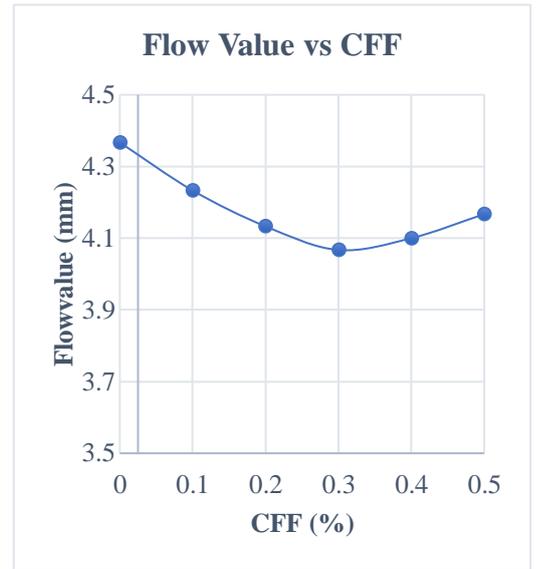
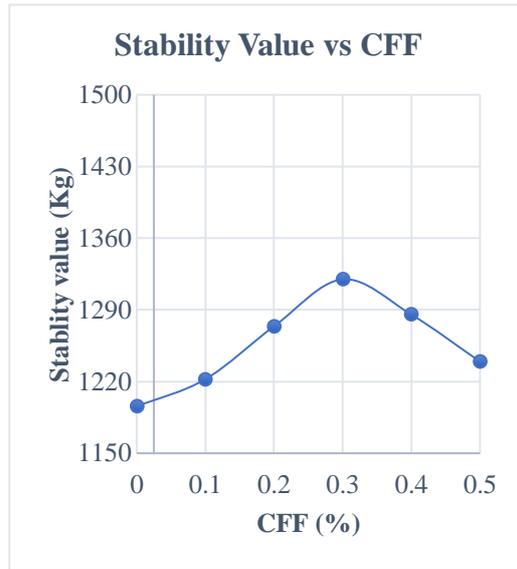
5.2 Modified Asphalt Mix Results

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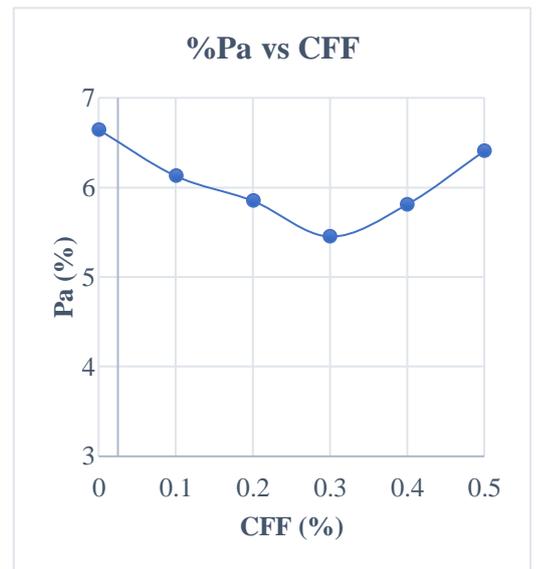
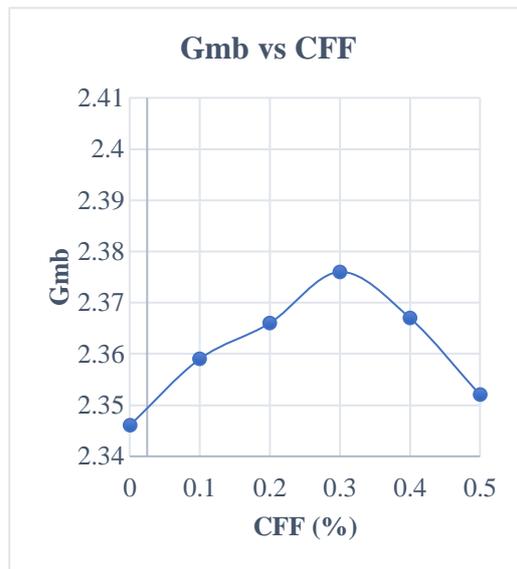
5.2.1 Carbon fibers fine (CFF) Modified Asphalt Mix

CFF (%)	Stability (kg)	Flow (mm)	Gmb	%Pa	VFB (%)	VMA (%)
0.0	1.195x10 ³	4.367	2.346	6.645	56.685	15.341
0.1	1.222x10 ³	4.233	2.359	6.128	58.795	14.872
0.2	1.273x10 ³	4.133	2.366	5.85	59.984	14.619
0.3	1.319x10 ³	4.067	2.376	5.452	61.762	14.258
0.4	1.285x10 ³	4.1	2.367	5.81	60.159	14.583
0.5	1.239 x10 ³	4.167	2.352	6.407	57.637	15.124

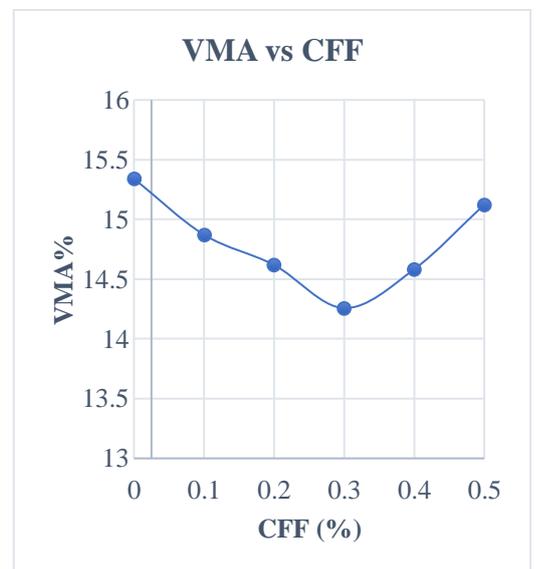
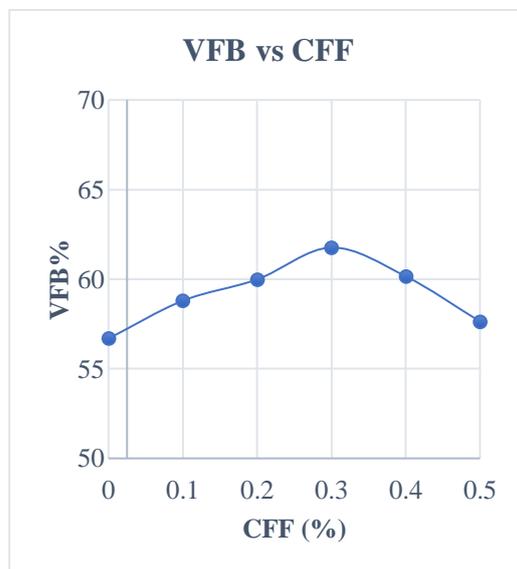
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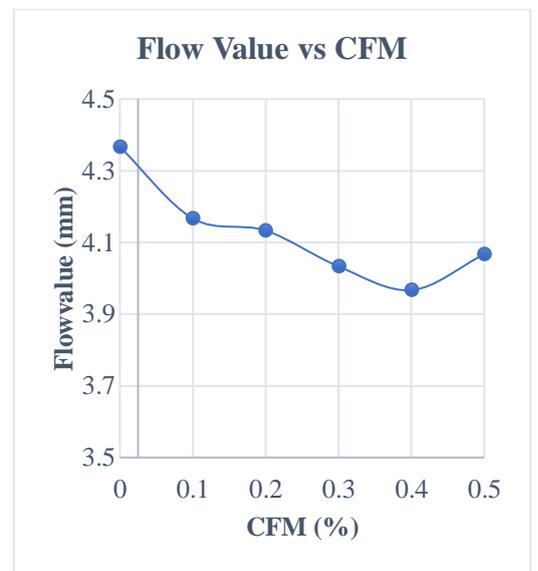
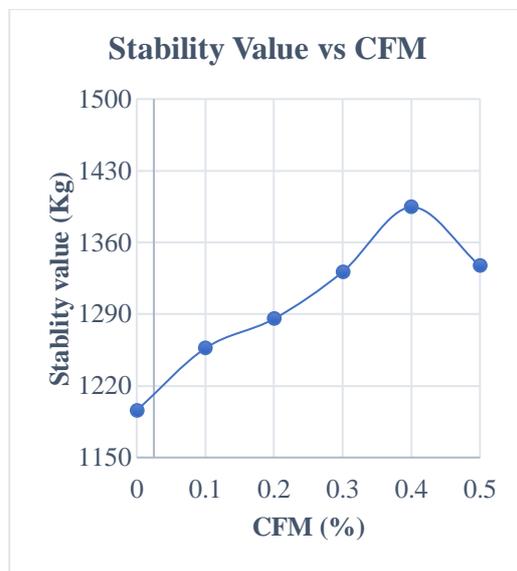


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5.2.2 Carbon fibers medium (CFM) Modified Asphalt Mix

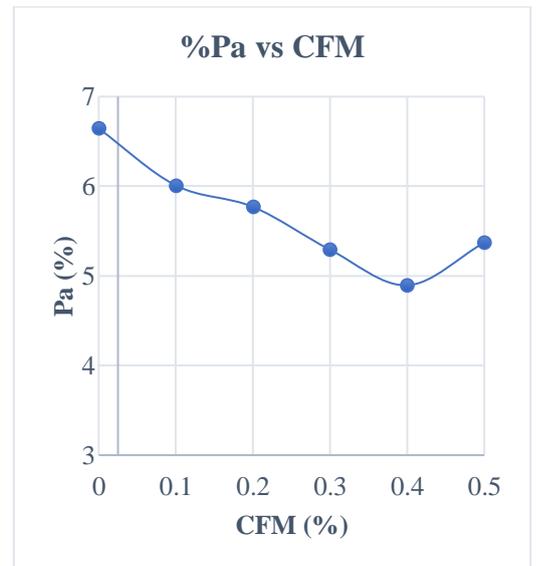
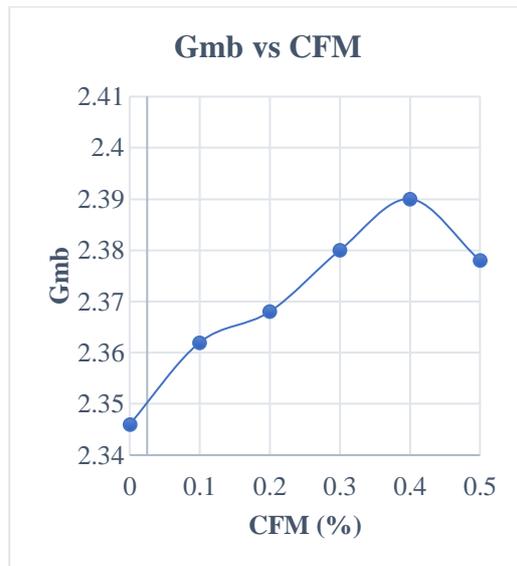
CFF (%)	Stability (kg)	Flow (mm)	Gmb	%Pa	VFB (%)	VMA (%)
0	1.195 x10 ³	4.367	2.346	6.645	56.685	15.341
0.1	1.256 x10 ³	4.167	2.362	6.009	59.297	14.763
0.2	1.285 x10 ³	4.133	2.368	5.77	60.335	14.547
0.3	1.331 x10 ³	4.033	2.38	5.292	62.505	14.114
0.4	1.394 x10 ³	3.967	2.39	4.895	64.408	13.753
0.5	1.337 x10 ³	4.067	2.378	5.372	62.132	14.186

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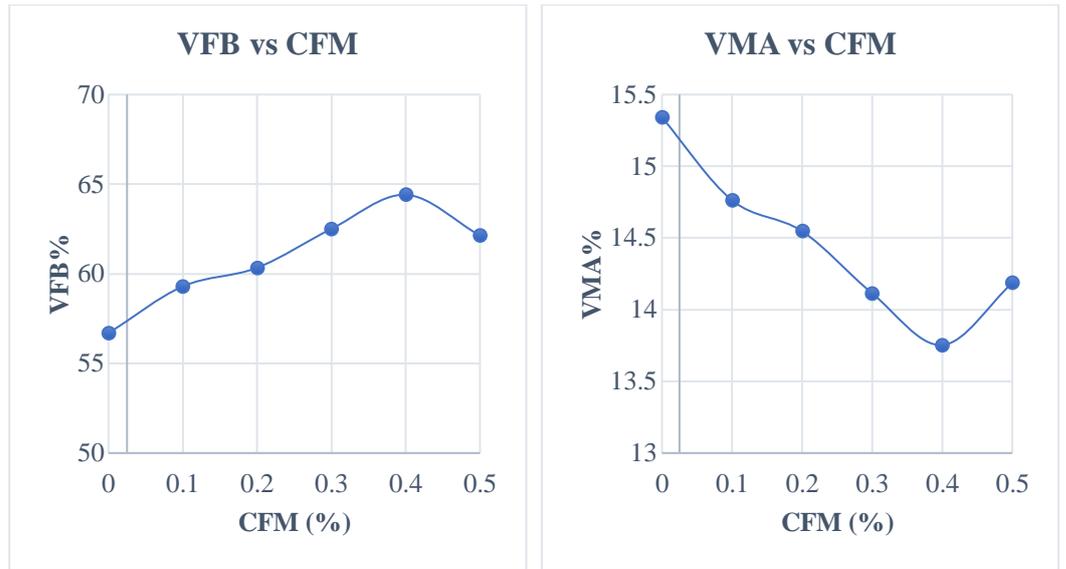
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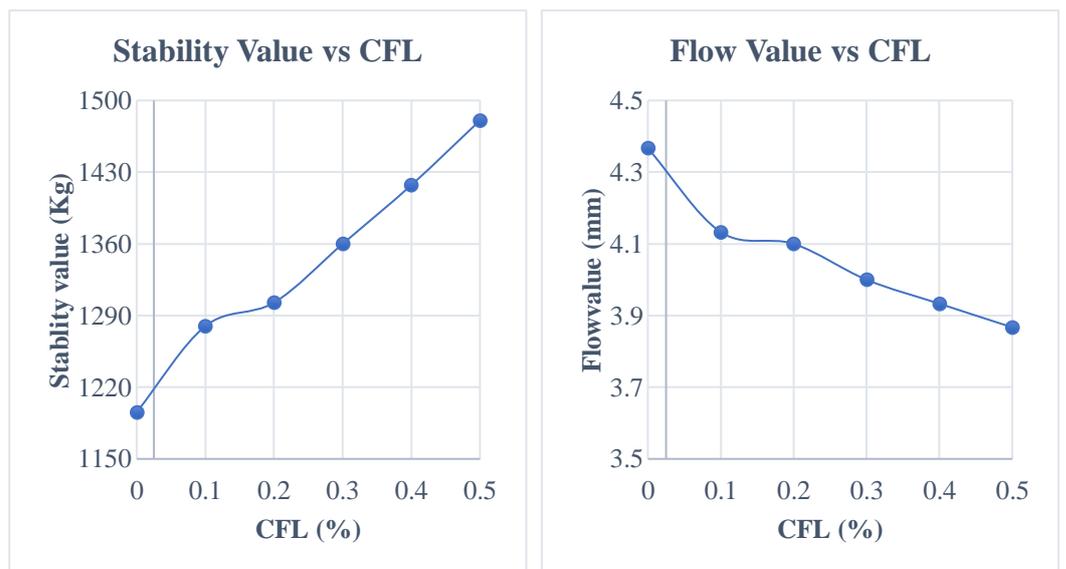
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5.2.3 Carbon fibers large (CFL) Modified Asphalt Mix

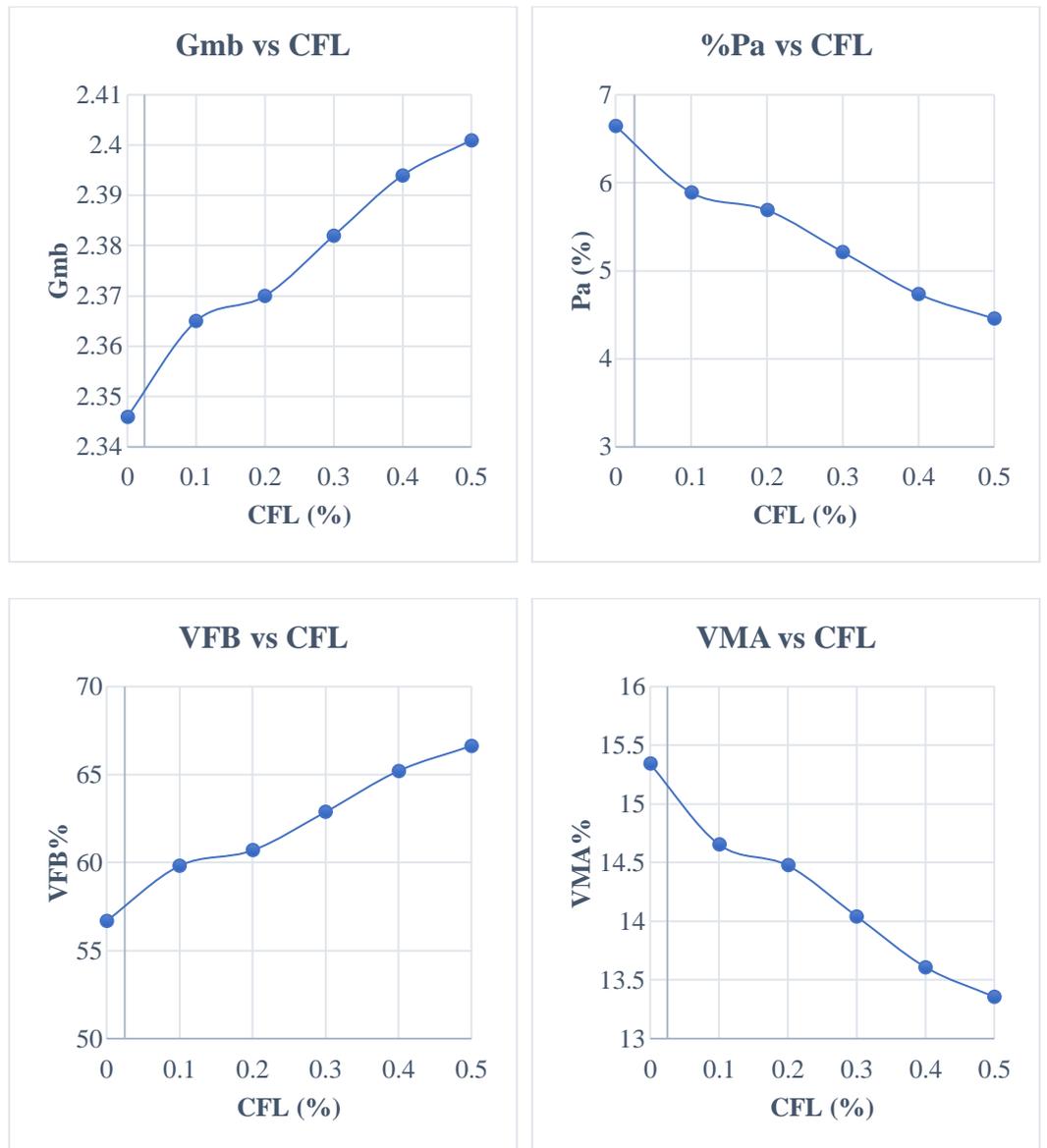
CFF (%)	Stability (kg)	Flow (mm)	Gmb	%Pa	VFB (%)	VMA (%)
0	1.195 x10 ³	4.367	2.346	6.645	56.685	15.341
0.1	1.279 x10 ³	4.133	2.365	5.889	59.816	14.655
0.2	1.302 x10 ³	4.1	2.37	5.69	60.691	14.475
0.3	1.359 x10 ³	4	2.382	5.213	62.876	14.042
0.4	1.417 x10 ³	3.933	2.394	4.735	65.207	13.609
0.5	1.480 x10 ³	3.867	2.401	4.457	66.629	13.356



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6. Conclusion & Recommendation

6.1 Conclusion

(a) CFF, CFM & CFL

The results are compared with conventional asphalt mix, where (+) increment and (-) decrement.

Parameter	Opt.dose	Stability	Flow	Gmb	%Pa	VFB	VMA
CFF	0.3%	30% +	14% -	2.61% +	14% -	5.71%+	5.52% +
CFM	0.4%	40% +	20% -	3.04% +	16% -	7.14% +	6.90% +
CFL	0.5%	50% +	24% -	3.48% +	18% -	8.57% +	8.97% +

(b) Effect of fiber percentages

- ✓ **Lower Dosages (0.1%–0.2%):** Carbon fiber addition at very low levels showed negligible improvement, as the fiber content was insufficient to provide effective reinforcement within the asphalt matrix.
- ✓ **Excessive Dosages (above optimum 0.3%–0.5%):** Higher fiber contents led to clustering, segregation, and reduced workability, ultimately diminishing the overall performance of the asphalt mixtures.

(c) Comparison with Conventional Mix

- ✓ **Performance Improvement:** Modified asphalt mixtures exhibited superior stability, density, and resistance to permanent deformation compared to conventional mixes.
- ✓ **Durability Enhancement:** The inclusion of carbon fibers decreased air voids and increased voids filled with bitumen (VFB), signifying improved durability and more efficient binder utilization.
- ✓ **Application-Specific Benefits:** Different fiber sizes provided distinct advantages; fine fibers were more suitable for moderate traffic conditions, whereas larger fibers offered reinforcement for heavy-duty pavements.
- ✓ **Overall Validation:** The findings confirmed that carbon fibers significantly enhanced both performance properties (stability and flow) and volumetric properties (Gmb, %Pa, VFB, and VMA) of asphalt mixtures.

6.2 Recommendation

- **Bitumen Grade:** The study utilized 60/70 penetration grade bitumen in all asphalt mixtures.
- **Scope of Fiber Dosages:** The investigation was restricted to carbon fiber contents between 0.1% and 0.5%; further studies may explore effects at other dosage levels.
- **Research Limitation:** The study focused only on short-term durability and performance, leaving long-term behavior of carbon fiber-reinforced asphalt for future research.

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Competing interests: The authors declared no competing interests.

Data Availability: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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