A PERFORMANCE COMPARISON OF BITUMINOUS CONCRETE WITH PELLETIZED CELLULOSE AND POLYESTER FIBERS

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ABSTRACT

The purpose of road pavement is to provide vehicles with a uniform running surface that has a high skidding resistance, strong against rutting, fatigue and durable too in all-weather condition for its design life. To meet the increasing demand for performance, a variety of additives used for enhancing the properties of bituminous mixtures. In this present research work, the main objective is to understand the engineering properties of the Bituminous Concrete (BC) mix with and without fiber. Two types of fibers are used in this study along with conventional mix, namely polyester and pelletized cellulose fiber. For preparation of the mixtures, aggregate gradation was adopted from MoRTH specifications, binder content has been varied regularly from 4.5% to 6.5% and fiber content 0.1%, 0.3% and 0.5% of total mix, the optimum fiber content was obtained at 0.3% from stability and volumetric analysis.

Keywords: Fiber Content, Optimum Binder, Marshall, Pelletized Cellulose Fiber, Polyester Fiber.

INTRODUCTION

Bituminous mixture performance improves in terms of stability against rutting and resistance against fatigue cracking. This paper tries to explain how they would evolve and how fibers help the performance in terms of fracture mechanics. The research work is based on the hypothesis that fracture energy and toughness of the material may be improved with fiber.

Alteration of the asphalt binder is one method considered to enhance pavement performance. Nowadays, some different resources that have been tried to emphasize Bituminous Concrete (BC). For enhancing the properties of BC mix, fibers and polymers are used. However, it has been demanded that among various modifiers for asphalt, fibers have gained significant attention for their refining properties. Construction of highway involves huge amount of resource. An exact engineering design may save sustainability as well as consistent performance of the in-service pavement can be attained. The present study is mainly focused on the mix design aspect. A correct design of BC mix is expected to have results which is adequately strong, durable, resistive to fatigue and permanent deformation. The present research work made an attempt to identify some of the issues involved in bituminous mix design.

1. Objective

The prime objective of the study is to understand the effects of fiber use in bituminous mixtures. The objectives of the study are presented in stage wise as:

- Characterization (aggregates and bitumen) used in the mixes.
- Marshall Mix deign of BC mix with two different fibers (polyester fiber and pelletized cellulose fiber).
- To estimate optimum binder content and optimum fiber content used in BC mix.
- To characterize the performance of modified BC mix with pelletized cellulose fibers and polyester fibers.

- Comparison of bituminous mix properties for both mixes at various bitumen contents.

2. Literature Review

The purpose of the fibers was to essentially stabilize the mixture and prevent bleeding of asphalt during hot weather. From the reviews of various works, scientists and engineers are trying to improve properties of asphalt mixtures, such as their stability and durability, by incorporating new additives either in the bitumen or in the asphalt mixture (Chen & Xu, 2010; Frigio et al., 2016; Golestani et al., 2015). Adding fibers to the binder or the bituminous mixtures ensures their stability and mechanical strength (Xiong et al., 2015). An appropriate quantity of fibers changes the properties of the asphalt, reducing the penetration and increasing the softening point. It changes the viscoelasticity of the bitumen as well (Mohammed et al., 2018). Fibers are a natural or synthetic material that are used in the manufacture of materials such as textiles or paper, and impregnated in materials such as cement and asphalt mixtures. Fibers in hot mix asphalt (HMA) act as a reinforcement. Fibrous reinforcement plays a role in ensuring strength, thermal stability, electrical conductivity and frictional properties of composites (Bijwe, 1997).

Engineers are constantly working on various aspects like major problems in roads, including permanent deformation, fatigue cracking and raveling. For this, the most frequently added materials are polymers, anti-stripping agents, crumb rubber, sulfur, asbestos, roofing shingles, slag and fly ash, among others (Mundt et al., 2009). Inclusion of fibers in the asphalt mixtures is gathering strength as they act as a reinforcement, adding ductility and tensile strength to the material due to the enhanced interlocking of aggregates. The interconnection between aggregates and fibers enables the material to withstand additional strain energy before cracking occurs; thereby, it is of great significance for extending the useful life of safer roads (Mahrez et al., 2005; Stempihar et al., 2012).

3. Methodology

In the present investigation, the methodology as shown in Figure 1 is adopted for evaluation of BC mix and to understand the effects of fiber usage in BC mixtures.

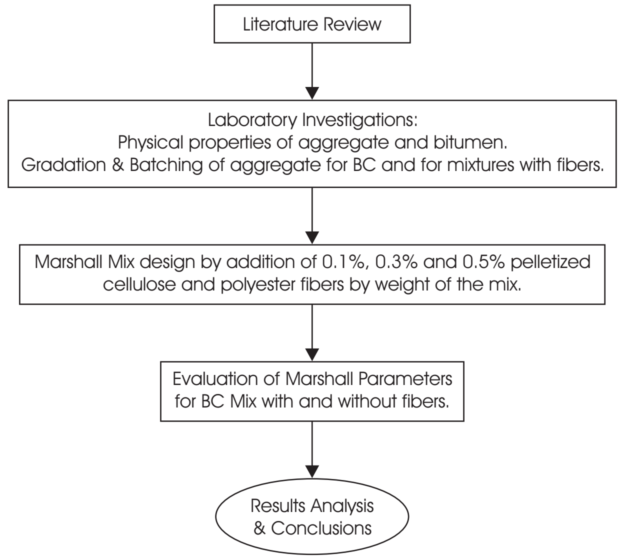

Figure 1. Methodology Adopted for the Study

4. Experimental Programme

The present investigation focuses on bituminous mixtures using different fibers, especially pelletized cellulose and polyester fibers. To perform the experimental investigation on bituminous mixes, the materials (ingredients of mix) used are aggregates and bitumen was tested for basic physical properties and the same is verified with the MS-2 (Asphalt Institute, 2014).

4.1 Marshal Test

The Marshall method is applicable for hot mix asphalt paving mixtures containing aggregates with maximum sizes of 25 mm or less. The Marshall method is used for determining the optimum binder content for a given mix and viscosity grade bitumen (VG 30) was used in the mix for this study. The test specimens were prepared for every 0.5% variation in bitumen content from 4.0-6.5% as specified in MoRTH procedure for BC mix (Ministry of Road Transport & Highways, 2013) and to this sample Marshall Mix Design was used by adding 0.1%, 0.3% and 0.5% pelletized cellulose and polyester fibers by weight, respectively. The magnitudes of the test specimens were 100 mm in diameter and 63.5 mm in height with an objective void content of 4 % (Asphalt Institute, 2014). Three test specimens were compacted for each percentage of binder content.

5. Results and Discussion

The experimental test results, finds of bituminous mixes are described for both BC mix with polyester fiber and pelletized cellulose fiber. The test results are analyzed for determination of optimum binder content (OBC) and optimum fiber content of bituminous mixes as per MoRTH procedure. With the obtained OBC a set of three samples were prepared to identify the bituminous mix properties as shown in the Figures 2 and Figure 3. Air voids and viscosity modifying admixtures (VMA) are important, in terms of stability. Therefore, capping the mixtures from air voids and VMA is important. Stability (strength) is the prime parameter of concern in the study. The study made an attempt to understand the relation between stability and binder content for different type of bituminous mixes.

5.1 Aggregates Gradation

Grade–II was adopted for BC mix as per Clause 509

Figure 2. Preparation of Mixture

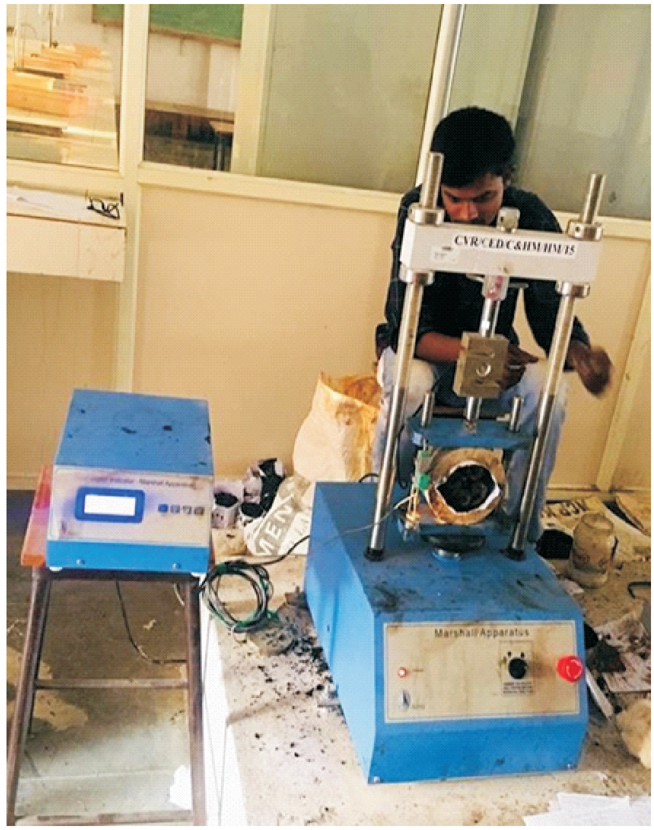

Figure 3. Marshal Stability and Flow Test

procedure, as given in Table 1. Aggregate, mineral aggregates, filler were used from the local quarry. The physical properties of aggregate were obtained through laboratory test are given in Table 2.

Aggregate materials were satisfied for preliminary test property as per MoRTH required for BC mix grade-II for conventional mix and with fiber mix.

5.2 Bitumen

The bitumen was tested in the laboratory for physical characteristics and its properties are given in Table 3.

5.3 Marshall Parameters

5.3.1 Bituminous Mixes

The results of experimental tests obtained for various properties of bituminous mixtures prepared using VG-30 grade bitumen are summarized in Figure 4.

From the Figure 4, it is observed apart from all, binder content is independent and governing parameters where it dictates all the mix parameters.

Gradation Table for Bituminous Grade-II									
Weight of Total Mix		1200 g		Aggregate Gradation for BC Grade II (50-65 mm Thickness)					
				Binder Content (% by weight of loose aggregates)					
Sieve Size (mm)	MORTH Mid-Point Gradation	% Retained	Cumulative Retained	4.0%	4.5%	5.0%	5.5%	6.0%	6.5%
19	100	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13.2	89.5	10.5	100	121.0	120.3	119.7	119.1	118.4	117.8
9.5	69	20.5	120.5	236.2	234.9	233.7	232.5	231.2	230.0
4.75	62	7	127.5	80.6	80.2	79.8	79.4	79.0	78.5
2.36	45	17	144.5	195.8	194.8	193.8	192.8	191.8	190.7
1.18	36	9	153.5	103.7	103.1	102.6	102.1	101.5	101.0
0.6	27	9	162.5	103.7	103.1	102.6	102.1	101.5	101.0
0.3	21	6	168.5	69.1	68.8	68.4	68.0	67.7	67.3
0.15	15	6	174.5	69.1	68.8	68.4	68.0	67.7	67.3
0.075	9	6	180.5	69.1	68.8	68.4	68.0	67.7	67.3
<0.075	0	9	9	103.7	103.1	102.6	102.1	101.5	101.0
	Weight of Bitumen (g)			48	54	60	66	72	78
			Total (g)	1200	1200	1200	1200	1200	1200

Table 1. Aggregate Gradation for Bituminous Concrete of Grade-II

Type of Test	Test Method	MoRTH Specification (%)	Laboratory Results (%)
Crushing test	IS:2386 (Part 4)-1963 (Bureau Indian Standard, 1963c).	30	19.4
Los Angeles abrasion test	IS:2386 (Part 5)-1963	40	24.6
Aggregate impact test	IS:2386 (Part 4)-1963 (Bureau Indian Standard, 1963c).	30	18.76
Shape test	IS:2386 (Part 1)-1963 (Bureau Indian Standard, 1963a).	30 (Combined Elongation & Flakiness Indices)	Elongation Index-14.6 Flakiness Index-6.33
Specific gravity test & water absorption test	IS:2386 (Part 3)-1963 (Bureau Indian Standard, 1963b).	2.6-2.9&≤1%	2.77 & 1%

Table 2. Physical Properties of Aggregates

Consistency Characteristics	Test Standards	Laboratory Values	Specifications (VG-30)
Penetration at 25oC,100 g, 5 s, 1/10 mm	IS:1203 (Bureau Indian Standard, 1978a)	62	60-70
Softening point (°C)	IS:1205 (Bureau Indian Standard, 1978b)	49.3	47 (minimum)
Ductility (cm)	IS:1208 (Bureau Indian Standard, 1978c)	100	>60
Flash point (°C)	IS:73 (Bureau Indian Standard, 2013)	250	220

Table 3. Bitumen properties

- The Marshal Stability (strength) value increases with an increase in binder content for a maximum of 40.748 kN and decreases. This is because the addition of bitumen makes the mixture less rigid, which lowers the stability value.
- The flow value consistently increases with an increase in binder content and reaches a maximum of 5.863 mm.
- The density also increases with an increase in binder content for a maximum of 2.376 g/cc and thereafter the density decreases gradually.
- The percentage of air voids steadily decreases with increasing binder content, ultimately reaching to the minimum void content of about 5.436%.
- The percentage of voids in the mineral aggregate (VMA) generally decreases to a minimum value, there after increases with increase in binder content to maximum of 11.428%.
- The percentage of voids filled with binder (VFB) steadily increases with increase in binder content, to a maximum of 53.893%.

5.3.2 Bituminous Mixes with Fibers

- Experiment test results and obtained bituminous mix properties of mixes prepared with two different fibers

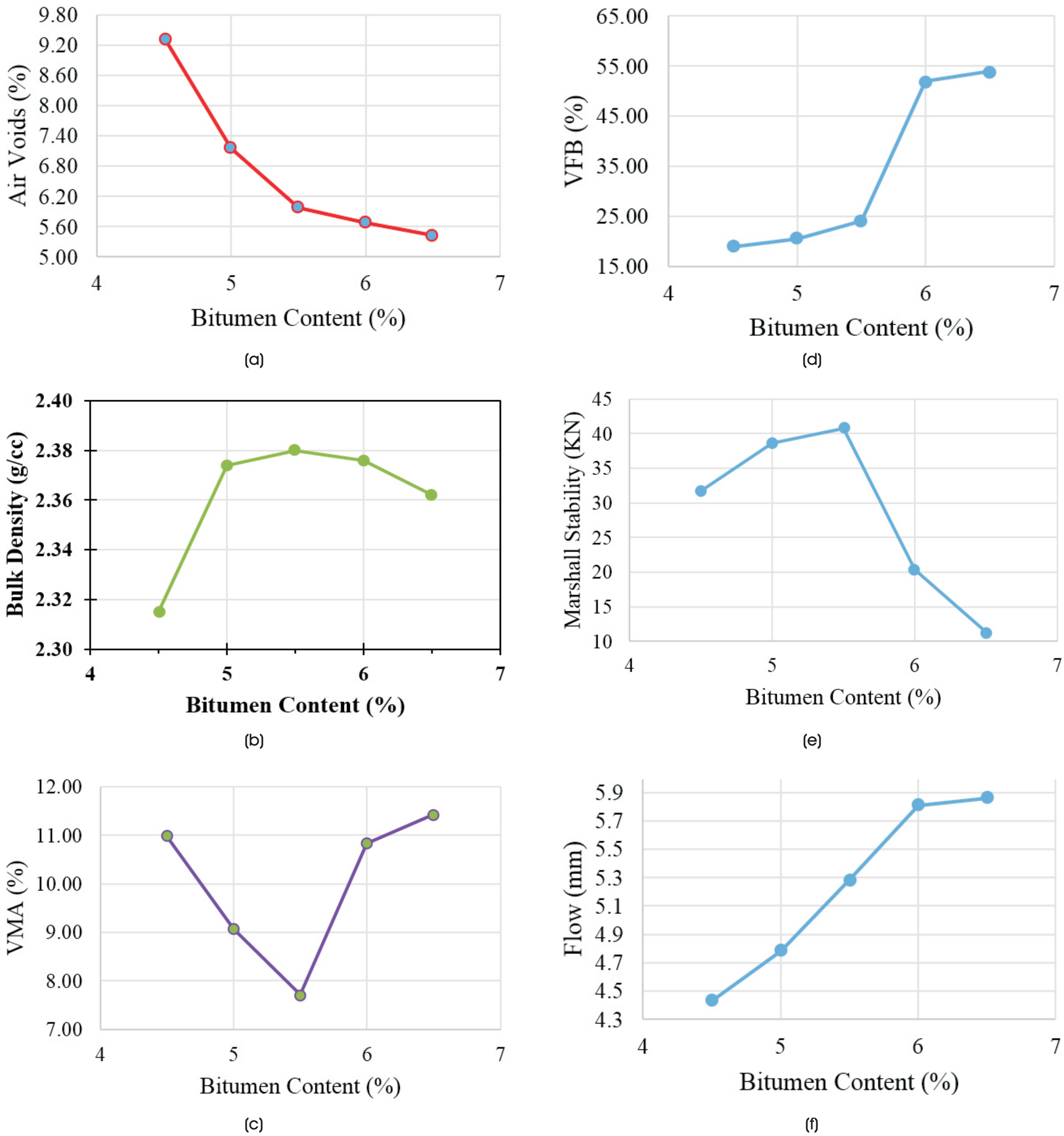

Figure 4. Marshall Test Results for Conventional HMA Mix - BC Grade - II (a) Air Voids (b) Bulk Density (c) VMA (d) VFB (e) Marshall Stability (f) Flow

(polyester fiber (PF) and pelletized cellulose fiber (PCF)) are given below in Figure 5 for the further analysis and discussion.

From the Figure 5, it is observed apart from all, binder content is independent and governing parameters where it dictates all the mix parameters.

- The stability (strength) value increases with an increase in binder content for a maximum of 42.057

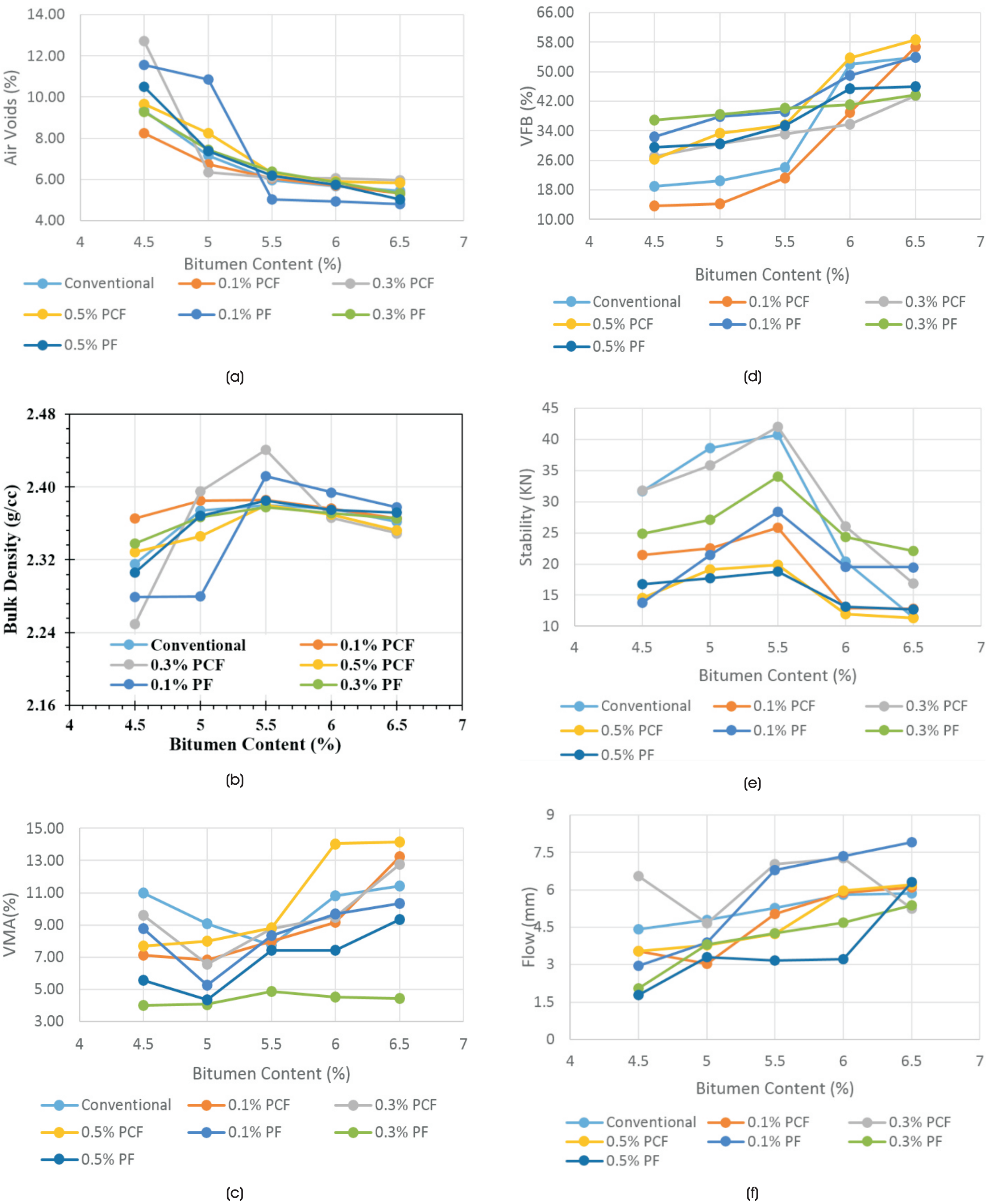

Figure 5. Marshall Test Results for Different % of Fiber Content (a) Air Voids (b) Bulk Density (c) VMA (d) VFB (e) Marshall Stability (f) Flow

kN and 34.016 KN with 0.3% pelletized cellulose fibers and 0.3% polyester fibers, respectively and decreases. This is because the addition of bitumen makes the mixture less rigid, which lowers the stability value.

- The flow value consistently increases with an increase in binder content and reaches a maximum of 6.1 mm, 7.265 mm and 6.205 mm with 0.1%, 0.3% and 0.5% pelletized cellulose fibers, respectively and 7.9 mm, 5.37 mm and 6.31 mm with 0.1%, 0.3% and 0.5% polyester fibers, respectively.
- The density also increases with increasing binder content for a maximum of 2.386 g/cc, 2.441 g/cc and 2.38 g/cc with 0.1%, 0.3% and 0.5% pelletized cellulose fibers, respectively and 2.412 g/cc, 2.378 g/cc and 2.385 g/cc with 0.1%, 0.3% and 0.5% polyester fibers, respectively and thereafter the density decreases gradually.
- The percent of air voids steadily decreases with increasing binder content, ultimately reaching to the minimum void content of about 5.327%, 5.969% and 5.831% with 0.1%, 0.3% and 0.5% pelletized cellulose fibers.

Conclusions

From this experimental study, the following conclusions are obtained based on various tests results:

Optimum binder content and optimum fiber content is found at 0.3% of both polyester and cellulose fiber, as the stability maximum at 0.3%. It is observed that HMA can be laid successfully at 1600C having a stability value of 40.748 KN for conventional mix. The stability has increased by 3.2% when added with cellulose pelletized fibers of 0.3% of the mix and the stability has decreased by16.52% when added with polyester fibers. The percentage of air voids steadily decreased with increasing fiber content and air voids for 0.1% cellulose fiber is obtained as 5.327% and for 0.1% polyester fiber is obtained as 4.808% at compaction temperature of 1000C, unlike conventional mix was 5.436% at compaction temperature of 1000C. The bulk density steadily increases and then decreases for further addition of fiber content and the density for conventional mix was 2.362 gm/cc whereas modified mix with 0.5% pelletized cellulose fiber has decreased to 2.352 gm/cc. It is observed that, the flow value of modified mixes are relatively lower as compared to the conventional mix. It has been found that the addition of polyester fiber in BC mix in lab work condition is very difficult, and therefore mechanical mixing is suggested.

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