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The Effectiveness of Liquid Polymers on Bitumen and How Polymers Change the Performance of its Mixes

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ABSTRACT

A road transportation system performing well offers its users with a high level of service. Many personnel consider that the most common and essential form of inland transportation is the road system. Development of the infrastructure for asphalt roads contributes significantly to the national economy. The long-term use of an assortment of predominantly solid modifiers mixed with bitumen above its melting point, in the 150–200 °C temperature range, has been referred to as asphalt modification. Another constraint is the separation of polymers from asphalt. PMB, created using a locally available liquid co-polymer, Vinyl Acrylic Co-polymer (VAC), is simple to mix with asphalt at low temperatures and quickly. The country's planned road building program, spraying operations like surface-dressing and paving in severely cold areas often use VG-10 bitumen instead of the older 80/100 Penetration grade. Bitumen emulsion and other modified bitumen products also benefit from its use. VG-30 bitumen is often utilized to construct ultra-sturdy pavements subjected to heavy vehicle activity. It may stand instead of a Penetration score of 60/70—requirements of Bitumen VG-40: VG-40 Bitumen is used in various applications. The ideal characteristics of bitumen are affected by the mix type and structure. Bitumen, in general, should have the following desired properties: Bitumen shouldn't be very sensitive to changes in temperature, remain stable even in extreme heat, and not crack even when frozen solid. One way to improve bitumen characteristics is to add 0.5 percent Vinyl Acrylic co-polymer. A novel formulation of the binder was created with better polymer compatibility with bitumen since there is no phase separation. In order to examine how modification affected VG-30's characteristics, a polymer-modified asphalt composition with 0.5% (w/w) polymer was examined. The liquid condition of the polymer causes the main binder to soften even further.

Keywords: Liquid Polymer, Vinyl Acrylic Co-Polymer (VAC), Bitumen, PMBs.

1.0 Introduction

Spraying operations like surface-dressing and paving in severely cold areas often use VG-10(Viscosity Grade) bitumen instead of the older 80/100 Penetration grade. Bitumen emulsion and other modified bitumen products also benefit from its use. VG-30 bitumen is often utilized to construct ultra-sturdy pavements subjected to heavy vehicle activity. It may stand instead of a Penetration score of 60/70—requirements of Bitumen VG-40: VG-40 Bitumen is used in various applications. The ideal characteristics of bitumen are affected by the mix type and structure. Bitumen, in general, should have the following desired properties: Bitumen shouldn't be very sensitive to changes in temperature, remain stable even in extreme heat, and not crack even when frozen solid. The bitumen must have an appropriate viscosity for mixing and compacting. This may be done by utilizing acceptable-grade cuts or emulsions, heating the bitumen and aggregates before mixing, or both. The sudden increase in wheel loads and the accompanying shift in weather patterns may be mitigated by adding a synthetic polymer binder to BC. Polymer modification is one way to extend the pavement's fatigue life, reduce rutting, and shield it from thermal cracking. A multiphase solution with a high concentration of asphaltenes is produced when asphalt is blended or mixed with a polymer. This creates a complicated internal structure, increasing the mixture's viscosity. The primary goal is to create low-cost, high-performance bituminous mixes by combining liquid polymer with fly ash. These mixes may then be used in the building and upkeep of bituminous roads. Below is a breakdown of what will be covered.

2.0 Research Objectives & Scope of Work:

The primary goal is to create low-cost, high-performance bituminous mixes by combining liquid polymer with fly ash. These mixes may then be used in the building and upkeep of bituminous roads. The following is an outline of the project's goals and objective to find the various parameters like

Characterization of VG-30, Characterization of liquid polymer modified bituminous, Lime and fly ash make a Job mix similar to traditional BC mixes, Preparation of Job mix for modified BC mixes with lime and fly ash and Performance evaluation of the BC mixes.

3.0 Research Methodology

The basic philosophy of using warm mix additive with reclaimed asphalt material is to compensate the effect of hardened binder obtained from the RAP so as to incorporate higher percentages of RAP without compromising with the properties as compared to that of HMA mix. In present study, performance evaluation was done for warm mix additive containing reclaimed asphalt material. WMA containing 0%, 25%, 50%, 75% RAP are to be evaluated. Marshall Mix design was carried out to as per MS-2, Asphalt mix design method to obtain the optimum binder content for each mix. The warm mix additive used in the study was Evotherm® 3G. For comparison HMA mix with 0% and 25% RAP are also to be evaluated and compared with above mix.

The methodology adopted in this study is described in the following steps:

3.1 Methodology Study

1. Characterization of various aggregates and binder with and without additive to be used in the study.
2. Collection of RAP material from the source and determination of average binder content of the RAP material.
3. Finding the gradation of the RAP and virgin aggregates and proportioning of material such that resultant gradation meets the requirement for DBM as per MoRT&H specifications (*5th Revision*).
4. Determination of dosage of Evotherm® and optimum binder content from mix design method.
5. Preparation of Marshall samples at optimum binder content for moisture susceptibility and performance testing.
6. Performance evaluation of warm mix additive incorporated mix containing 0%, 25%, 50%, and 75% RAP material. For comparison HMA mix containing 0% and 25% RAP content were also considered.

The flowchart of proposed methodology is given in **Fig 3.1**.

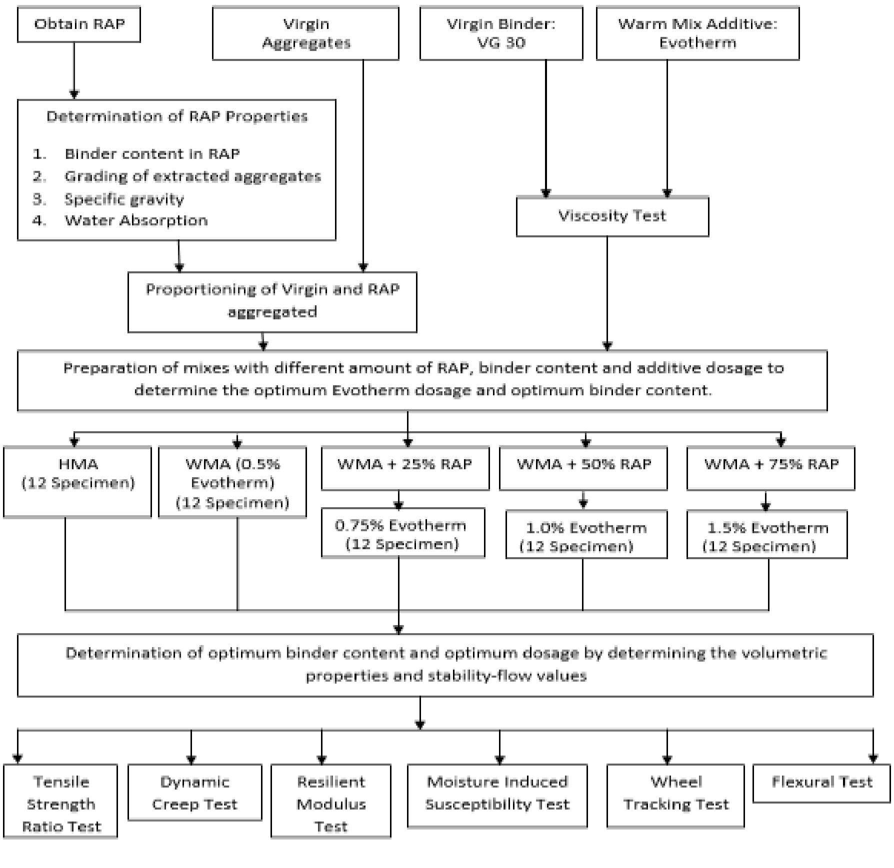


Fig 3.1: Flow chart of the methodology adopted

4.0 Experimental work

The granular component of bituminous concrete mixes, known as the aggregate, is responsible for the majority of the material's load-bearing and strength properties. As a result, it is important to regulate the aggregates' quality and physical attributes to make sure the pavement turns out well. Below are some of the qualities that aggregates for pavement should have:

First, aggregates shouldn't be too flexible. Swelling and adherence of bitumen to the rock may be caused by the presence of clay particles in the bituminous mix, which might lead to stripping issues. The maximum allowable percentage of clay lumps and friable particles is 1%. Sulphate soundness testing is a good way to evaluate durability or weather resistance. There should be no more than 1.2 parts dust to every 1-part asphalt cement by mass. The maximum specific gravity of bituminous concrete mixtures should be determined using AASHTO T-209.Coarse aggregates are defined as those that pass through a Sieve with a pore size of 4.75 millimeters. Crushed rock that has been screened to remove dust, clay, plants, and organic materials is the ideal coarse aggregate. The following characteristics should be present. The best option for fine aggregate is screened, clean quarry dust. Clay, loam, plants, and other organic materials shouldn't be present. The following characteristics are desirable in fine aggregates.

Table -4.1(a) of the Ministry of Roads and Highways' Fifth Revision, 2013 specifies the properties that coarse and fine aggregates used to make BC (Grade I) mix must meet. Table-4.1(a) displays the aggregates' test results from this research.

Table-4.1(a) Bituminous Concrete's Coarse Aggregate Material Properties

Property of materials	Test Results	Specification as per MoRTH ,2013	Value obtained
Particle Shape	Combined Flakiness value and Elongation Indices value	Maximum 35%	25%
Durability	Soundness in Sodium sulphate	Maximum 12%	9%
Absorption of water	Absorption of water	Maximum 2%	0.35
Stripping of bitumen	Coating and Separation of Bitumen Aggregate Mix	Minimum coating accumulation 94.5%	97%
hydric Sensitivity	Strength in Tension Retained	Min 80.5%	82%

Test characteristics for bitumen VG-30 according to IS-73, 2013 are listed in Table 4.1(b).

Table 4.1(b). Bituminous (VG-30) Material Characteristics

Property Tested	Test Result Outcomes	IS 73:2013 VG-30 Requirement
At typical circumstances (25°C, 100g, 5s), penetration is 0.1mm.	64	42.5(Minimum)
Temperature at which R&B softens. in degrees Celsius	48	47.6(Minimum)
Value of Absolute Viscosity at 60 degrees Celsius	2570	2400(Min)
Kinematic Viscosity,135°C, cSt	725	350(Min)
Solubility in trichloroethylene, % by mass	99.34	99.0(Min)
Viscosity ratio at 60°C, Test on residue from thin –film oven test/RTFOT	3.5	4.0(Max)
Flexibility in a 25 C thin-film oven test/RTFOT	52	40(Min)

The liquid polymer used in this thesis was purchased from Innovative Marketing Solutions (IMS). Binder modification at a dose of 0.5% to 1% (w/w of Bitumen) was also confirmed by the supplier. It was determined to integrate a 0.5% dose of liquid polymer to adjust the characteristics of the VG-30 binder based on the knowledge obtained from modifying the VG-10 binder with the same polymer. The following is an example of the change process:

Procedure: The bitumen was heated to 120 degrees Celsius, and then 5% liquid polymer was added to it. At this temperature, the mixture was stirred for 30-40 minutes. The manufactured liquid polymer modified binder (LPMB) is subsequently analysed to IRC-SP- 53, 2010 standards.

Table 4.1(c). Material test results

		Specified Value for the bitumen as per IRC SP- 53- 2010

Property Tested	Test Value obtained	Highest mean Temp (<20°C). and Lowest mean temp > -10 < - 10	Highest mean Temp (<20°C to 35°C). and Lowest mean temp > -10 < - 10	Highest mean Temp Above 35°C. and Lowest mean temp > -10
Penetration at 25 degrees C, 0.1 mm, 100 g, and 5 seconds.	69	60 to 120	50 to 80	30 to 50
The melting point (R&B), °C, Min.	53	50	55	60*
Minimum Complex Modulus (in kPa per radian per second, G/sin£) at 10 radian per second, Celsius	78	58	70	76
Distance between melting points (R&B), Celsius, Upper limit.	1	3	3	3
Viscosity Test at 150°C, Poise	3.75	1-3	3-6	5-9

Table 4.1(c) displays a comparison between the characteristics of VG-30 and those of a modified binder that includes 0.5% liquid polymer. Properties of LPMB with 0.5% liquified polymer/s, tabulated

5.1 Marshall Method's Contribution to the Mix Design

When properly built, a bituminous mix can support heavy traffic even in inclement weather, and it can also meet the requirements of structural and pavement surface quality. The design of the bituminous mix involves doing many trial mixes in order to get the optimal combination in terms of cost. The gradation of the aggregate, as well as the proportion of the binder that corresponds to it, should be such that the mix that is produced satisfies the requirements listed below. The right quantity of binder to generate a durable pavement by coating the aggregate in an impermeable layer and binding the particles together during compaction. Enough stability to provide resistance to deformation in the face of stresses that are either sustained or repeatedly applied. This resistance in the combination comes from the aggregates interacting with one another and the cohesion that normally arises as a result of the binder in the mixture. Capable of withstanding bending and mixing without developing cracks due to a lack of rigidity. It is vital to have the appropriate quantity and grade of bitumen in order to get the required level of flexibility. There should be enough voids in the whole mix that was compacted to give room for further compaction when the mix is loaded with traffic. Sufficient workability to allow for an effective construction operation in the laying of the mixture of pavement.

The Marshall Method, developed by Mississippi State Highway Department bituminous engineer Bruce Marshall, mixes bitumen. A bituminous mixture cylinder is loaded at 5 cm/min to assess its plastic deformation resistance. Testing develops and evaluates bituminous pavement mixes. This approach to blending has two primary features. Two examples are stability-flow testing and void-density testing.

Table 5.1 Aggregate Gradation and Blend Proportion for BC Layer with Lime

Sieve Size	Particle size distribution over a cutoff screen						
	The aggregate nominal size					Proportion of A, B, C, D, and E by Total Blend Weight 12:22:24: 40:2	Specified Limits for 50mm BC (MORTH,2013)
	A 20mm	B 10mm	C 6mm	D granulated Stone	E Lime		
19	100.00	100.00	100.00	100.00	100	100	100
13.2	30.00	99.00	100.00	100.00	100	91.38	90-100
9.5	10.23	61.00	100.00	100.00	100	80.65	70-88
4.75	0.00	4.00	70.00	100.00	100	59.68	53-71
2.36	0.00	0.00	36.00	97.00	100	49.44	42-58
1.18	0.00	0.00	10.32	79.00	100	36.08	34-48

0.6	0.00	0.00	8.92	55.00	100	26.14	26-38
0.3	0.00	0.00	0.00	42.00	99.4	18.79	18-28
0.15	0.00	0.00	0.00	26.00	96	12.32	12-20
0.75	0.00	0.00	0.00	13.00	64	6.48	4-10

Marshall's Stability—the largest stress a compressed specimen can bear at 60 degrees Celsius—measures mix strength. Bituminous pavement is especially sensitive at this temperature. This change is monitored during the course of the loading process. A connected dial gauge measures the specimen at the point of material failure during the loading process. This value is referred to as the flow value. The volumetric features of the mix are used in the carrying out of the density-voids study. The design of a bituminous mix may be broken down into the following phases. Choice of grading system to be used. Choosing which aggregates to consider. Both the aggregate mixture's and the asphalt cement's specific gravities will be calculated. Preparation of samples with varying concentrations of bitumen (in 0.5 percentage point increments).

Once the samples have been compressed, their specific gravities may be determined. Test for each specimen's level of stability. Perform the calculations necessary to determine the proportion of vacancies, VMA, and voids that have been filled with bitumen in each specimen. The determination of the optimal bitumen content based on the data that was gathered. Determine the ideal binder content by comparing the Marshall Stability, Flow, Voids in the whole mix, and voids filled with the bitumen to the design specifications.

5.2 Formulation for a Traditional BC Mix with Lime (Mix-A)

Table 3.4 shows the outcomes of the trial-and-error method, including the gradation of the selected component aggregates and their proportioning. The gradation that was constructed together with the constraints that were stated may be seen in Table 5.1Aggregate Gradation and Blend Proportion for the BC Layer with Lime.

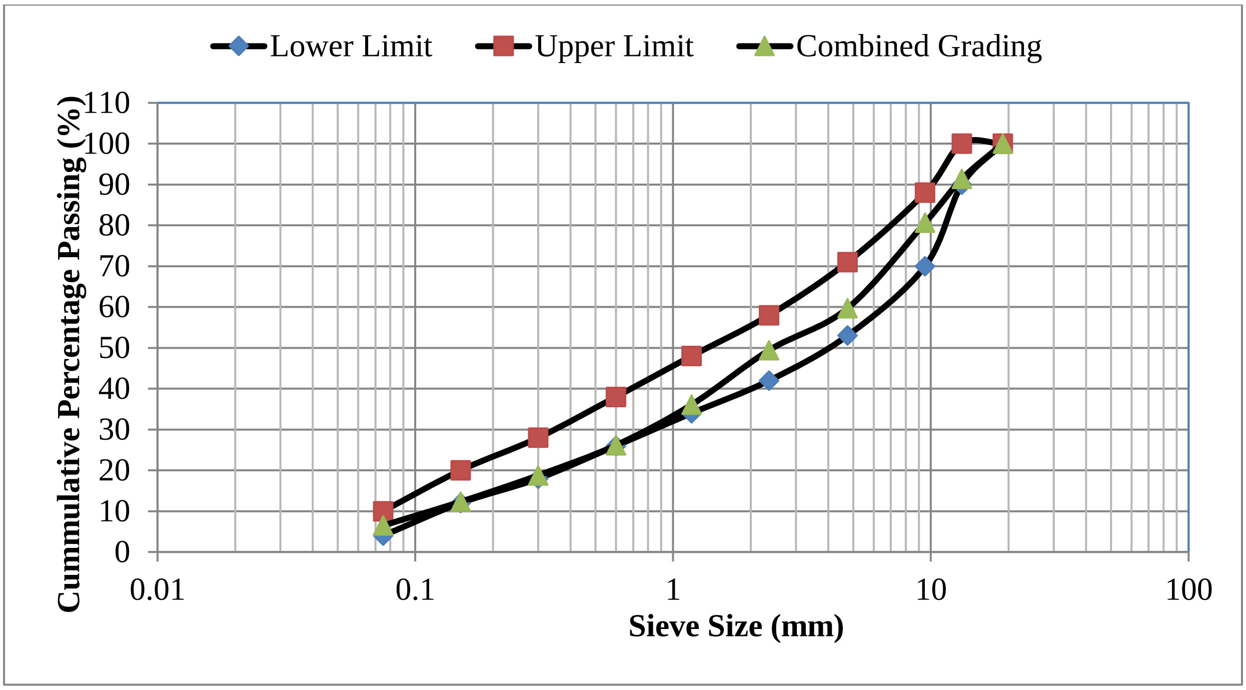


Figure 5.1 Gradation Adopted and Specified Limits for BC Mix

5.3 Establishing the Optimum Binder Content (OBC) of the Mixture

The OBC was calculated by experimenting with several ratios of VG-30 bitumen in Marshall samples (from 4.5 to 6.0%). After that, we measured and reported in Table 5.1 a number of volumetric metrics such bulk density, Marshall Stability, Flow, and more. The relationship between binder concentration, density, volume, and Marshall stability and flow is shown in Figure 5.2 The OBC is 5.1% of the total weight of the aggregate, as calculated by experts.

Table 5.2 Volumetric and Mechanical Parameters Obtained for Conventional BC with Lime

Aggregate weight, % binder	Density of the Bulk, in gm/cc	Stability (kN)	Flow Value (mm)	Air Voids, %	Insufficient Mineral Concentration VMA	Bitumen Used to Fill Vacancies, %
4.5	2.37	12.42	2.98	4.65	15.55	68.76
5.0	2.38	14.98	3.09	4.06	14.50	73.31
5.5	2.37	15.03	3.37	3.76	16.15	76.69
6.0	2.36	11.02	3.73	3.62	16.94	78.62

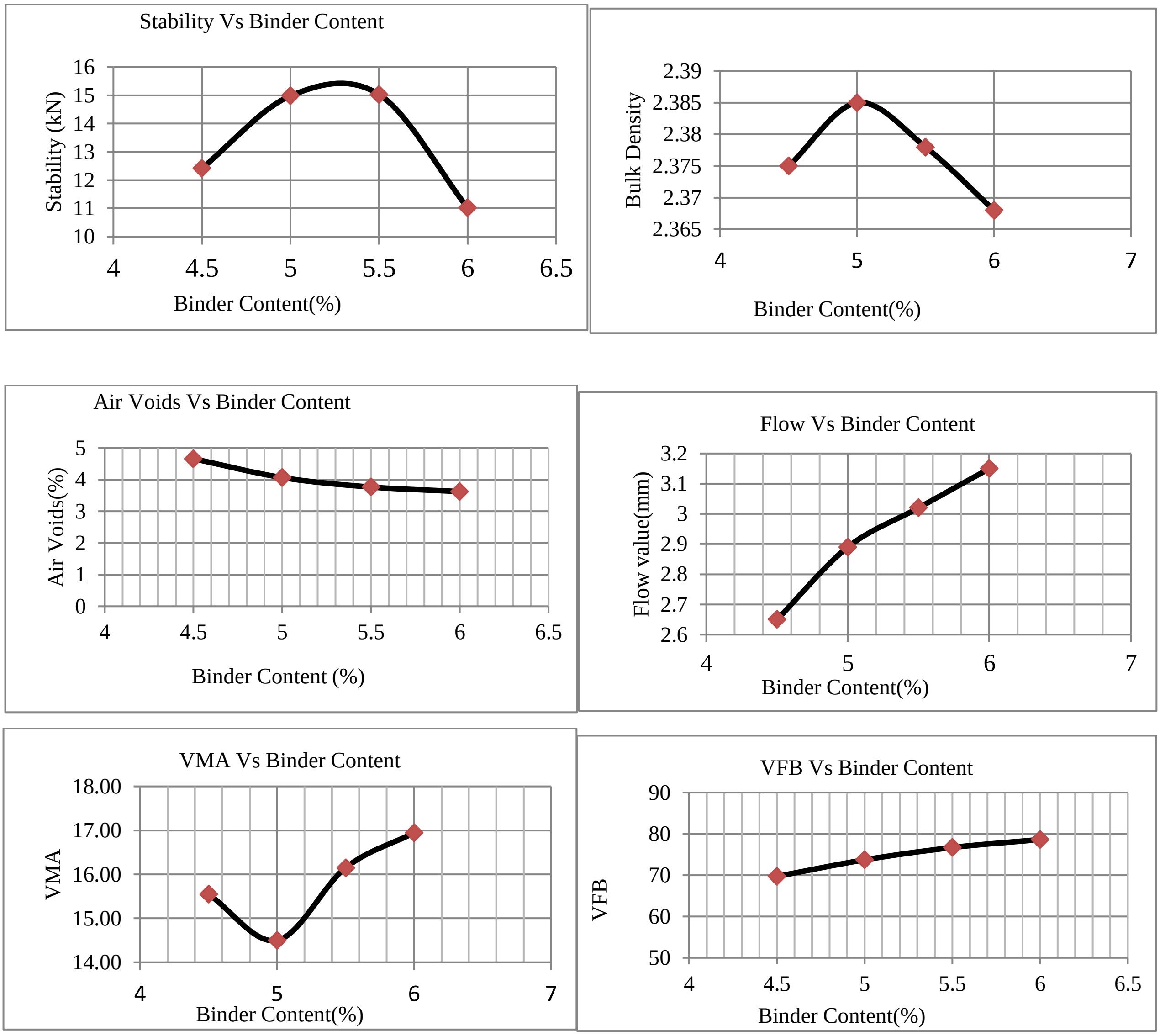


Figure 5.2 Properties of mix with respect to binder content

5.4 Plan for the production of a conventional BC Mix Containing fly ash (Mix-B)

Table 5.3presents the results of using the trial-and-error approach to determine the individual gradations of aggregates and fly ash, as well as their proportioning. The gradation that was constructed together with the constraints that were stated may be seen in Figure 5.3

Table 5.3 Aggregate Gradation and Blend Proportion for BC Layer with Fly Ash

Sieve Size	The fraction of particles that are finer than a certain screen size						
	Size designation for aggregates					Mix Ratio (A: B: C: D: E) by Total Mass 12:16:24: 38:7	Specified Limits for 50mm BC (MORTH,2013)
	A 20mm	B 10mm	C 6mm	D Stone Dust	E Fly ash		
19	100.00	100.00	100.00	100.00	100.00	100	100
13.2	30.00	99.00	100.00	100.00	100.00	91.44	90-100
9.5	10.23	61.00	100.00	100.00	100.00	82.99	70-88
4.75	0.00	4.00	70.00	100.00	100.00	64.54	53-71
2.36	0.00	0.00	36.00	97.00	100.00	53.58	42-58
1.18	0.00	0.00	10.32	79.00	100.00	39.81	34-48
0.6	0.00	0.00	8.92	55.00	100.00	30.31	26-38
0.3	0.00	0.00	0.00	42.00	100.00	22.96	18-28
0.15	0.00	0.00	0.00	26.00	80.00	15.48	12-20
0.75	0.00	0.00	0.00	13.00	40.00	7.74	4-10

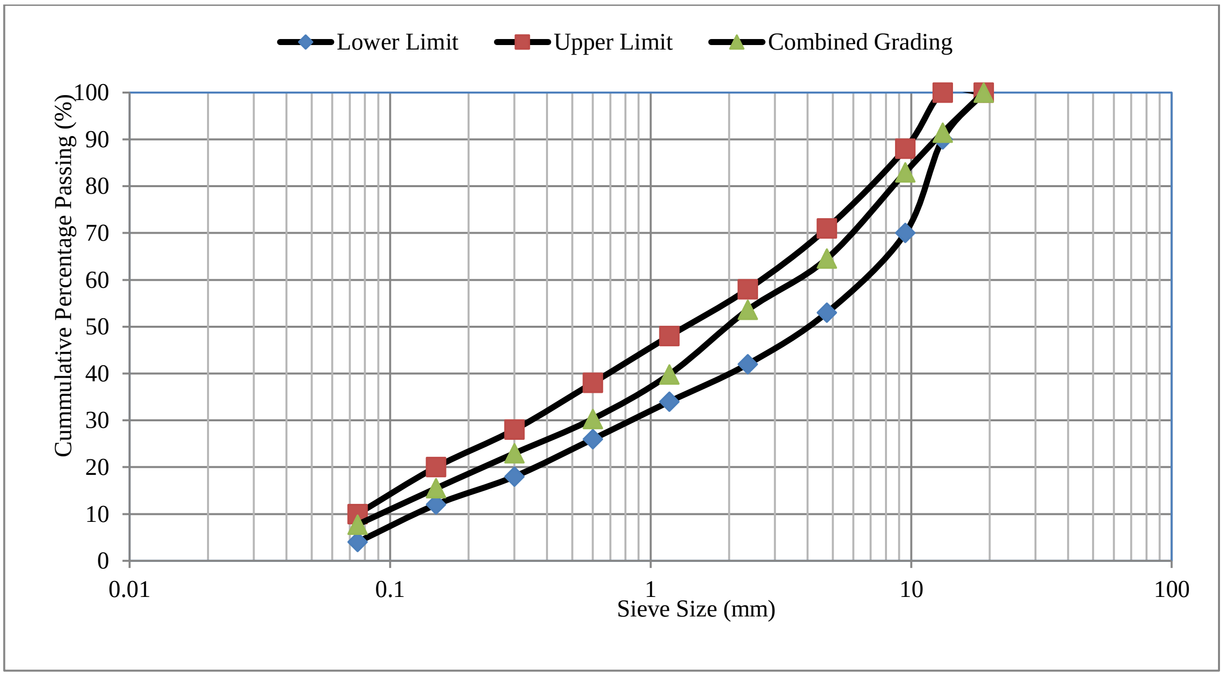


Figure 5.3 Gradation Adopted and Specified Limits for BC Mix

5.5 Determining the Optimal Binder Concentration (OBC)

By adjusting the percentage of VG-30 bitumen in Marshall samples, the OBC may be determined. Figure 5.4 provides a graphical representation of the test data received. The Optimal Binder Content (OBC) for aggregates was calculated to be 5.2% by weight based on the aforementioned criteria

Table 5.4 In conventional boilers with fly ash, the following volumetric and mechanical parameters were obtained

Aggregate Binder Content (%)	Mass per unit volume (g/cc)	Stability (kN)	Flow Value (mm)	Air Voids, %	Void Percentage in Mineral Aggregates	% Volume of Bitumen Used to Fill Vacancies
4.5	2.42	12.35	2.56	5.09	14.09	63.81
5.0	2.44	15.65	3.01	4.11	13.68	69.79
5.5	2.43	17.85	3.56	3.57	14.32	75.05
6.0	2.41	15.65	3.98	3.21	15.47	79.23

Figure 5.4 provides a graphical representation of the test data received. The Optimal Binder Content (OBC) for aggregates was calculated to be 5.2% by weight based on the aforementioned criteria

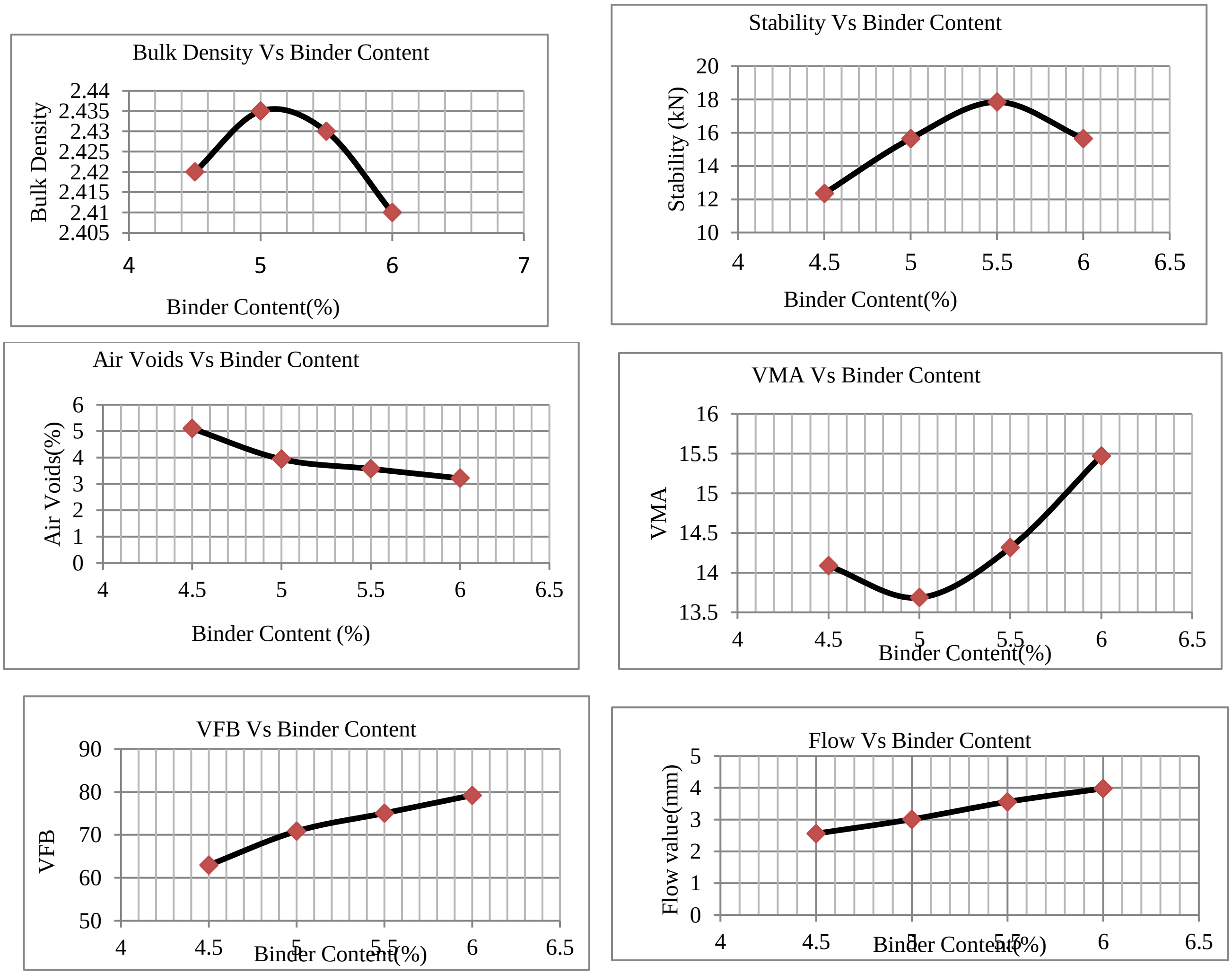


Figure 5.4 Properties of mix with respect to binder content

5.6 Plan for the Construction of Polymer-Modified BC Mix with Lime (Mix-C)

Table 5.5 provides the individual gradation of the component aggregates that were picked, together with their proportioning that was established via the approach of trial and error. The gradation that was constructed together with the constraints that were stated may be seen in table 5.5.

Table 5.5 Gradation of aggregates and proportion of blends.

Sieve Size	The fraction of particles that are finer than a certain screen size						
	Size designation for aggregates					Mix Ratio (A: B: C: D: E) by Total Mass 12:22:24: 40:2	Maximum and Minimum Values for 50 mm BC (MORTH, 2013)
	A 20mm	B 10mm	C 6mm	D Stone Dust	E Lime		
19	100.00	100.00	100.00	100.00	100	100	100
13.2	30.00	99.00	100.00	100.00	100	91.38	90-100
9.5	10.23	61.00	100.00	100.00	100	80.65	70-88
4.75	0.00	4.00	70.00	100.00	100	59.68	53-71
2.36	0.00	0.00	36.00	97.00	100	49.44	42-58
1.18	0.00	0.00	10.32	79.00	100	36.08	34-48
0.6	0.00	0.00	8.92	55.00	100	26.14	26-38
0.3	0.00	0.00	0.00	42.00	99.4	18.79	18-28
0.15	0.00	0.00	0.00	26.00	96	12.32	12-20
0.75	0.00	0.00	0.00	13.00	64	6.48	4-10

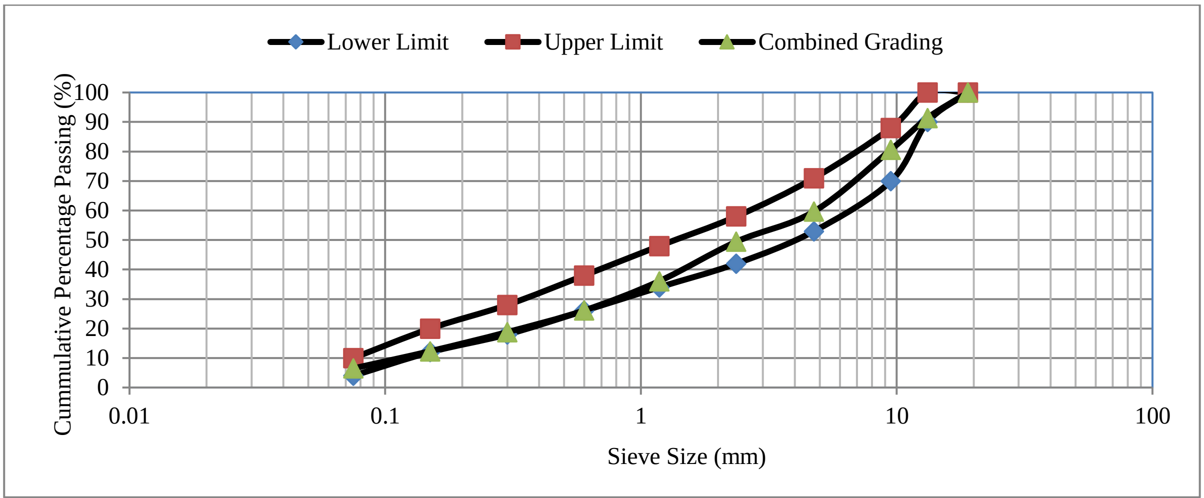


Figure 5.5 Presents the Specification Limits and Adopted Gradations for the BC Mix.

5.7 The Process of Determining the Optimal Binder Content (OBC) Marshall in order to determine the OBC.

Samples were generated with varying concentrations of VG-30 bitumen. The obtained test results are plotted against time and shown graphically in Figure 5.6. The above considerations led to a conclusion that 5.3% (by weight) of aggregates should consist of binder.

Table 5.6 After treating LPMB with lime, the following volumetric and mechanical parameters were determined

Aggregate Binder Content (%)	Mass per unit volume (g/cc)	Stability (kN)	Flow Value (mm)	Air Voids, %	Vacancies in Mineral Particles, or VMA	% Volume of Bitumen Used to Fill Vacancies
4.5	2.352	11.79	2.22	5.54	16.19	65.76
5.0	2.363	13.14	2.29	4.33	15.92	72.79
5.5	2.374	13.5	2.91	3.49	16.29	78.54
6.0	2.365	11.02	3.19	3.07	17.05	81.97

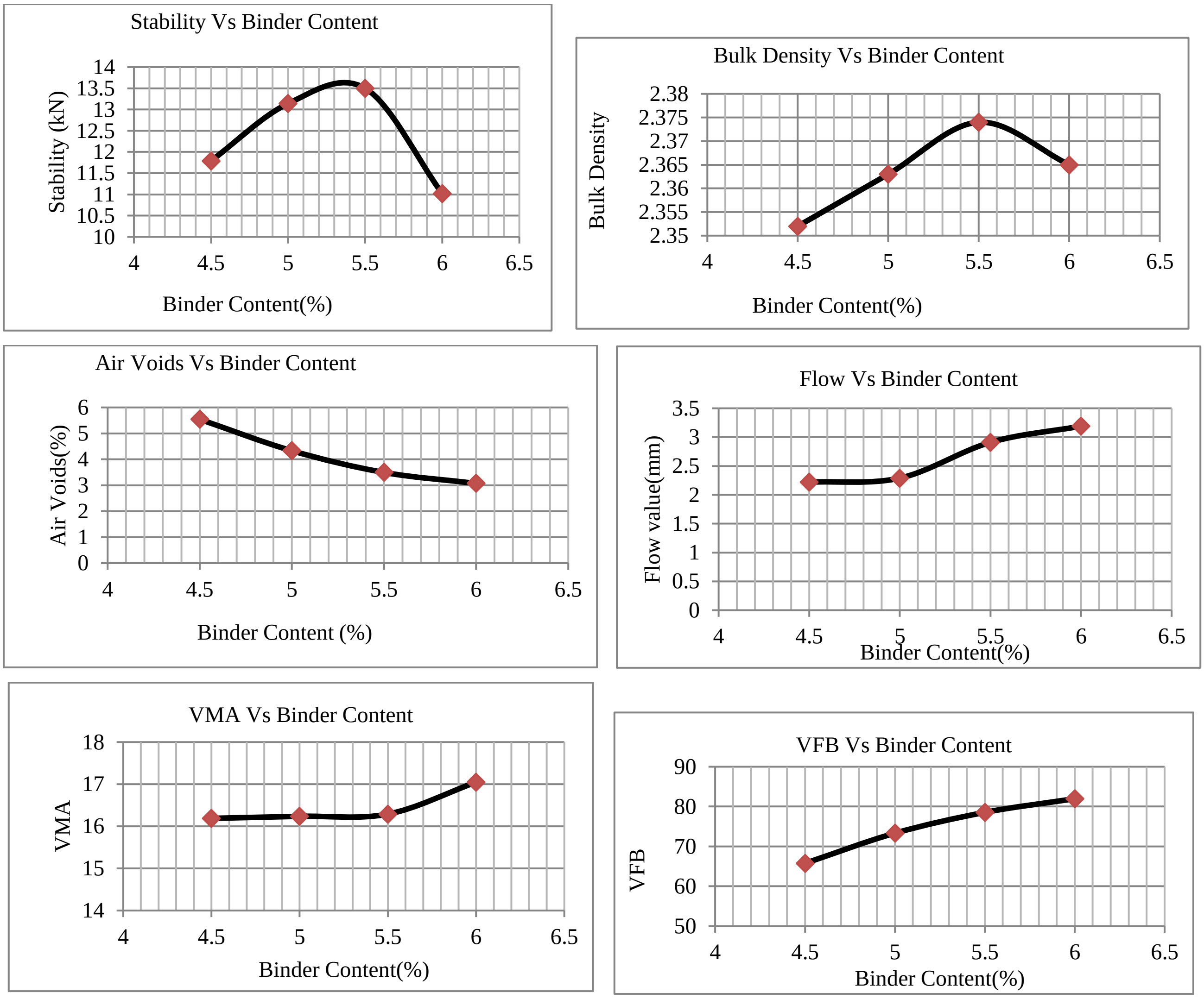


Figure 5.6 Properties of mix with respect to binder content

5.8 The design for the polymer-modified BC mix with fly ash (Mix-D)

Table 5.7 displays the results of a trial-and-error process to determine the gradation of selected component aggregates and the proportioning of those aggregates. Figure 5.7 displays the created gradient with the imposed limitations.

Table 5.7 Proportion of Blends to Aggregates.

Sieve Size	The number of particles that are smaller than the opening size of the sieve						
	Nominal size of aggregates					Mix Ratio (A: B: C: D: E) by Total Mass 12:16:24: 38:7	Specified Limits for 50mm BC (MORTH,2013)
	A 20mm	B 10mm	C 6mm	D Stone Dust	E Fly Ash		
19	100.00	100.00	100.00	100.00	100.00	100	100
13.2	30.00	99.00	100.00	100.00	100.00	91.44	90-100
9.5	10.23	61.00	100.00	100.00	100.00	82.99	70-88
4.75	0.00	4.00	70.00	100.00	100.00	64.54	53-71
2.36	0.00	0.00	36.00	97.00	100.00	53.58	42-58

1.18	0.00	0.00	10.32	79.00	100.00	39.81	34-48
0.6	0.00	0.00	8.92	55.00	100.00	30.31	26-38
0.3	0.00	0.00	0.00	42.00	100.00	22.96	18-28
0.15	0.00	0.00	0.00	26.00	80.00	15.48	12-20
0.75	0.00	0.00	0.00	13.00	40.00	7.74	4-10

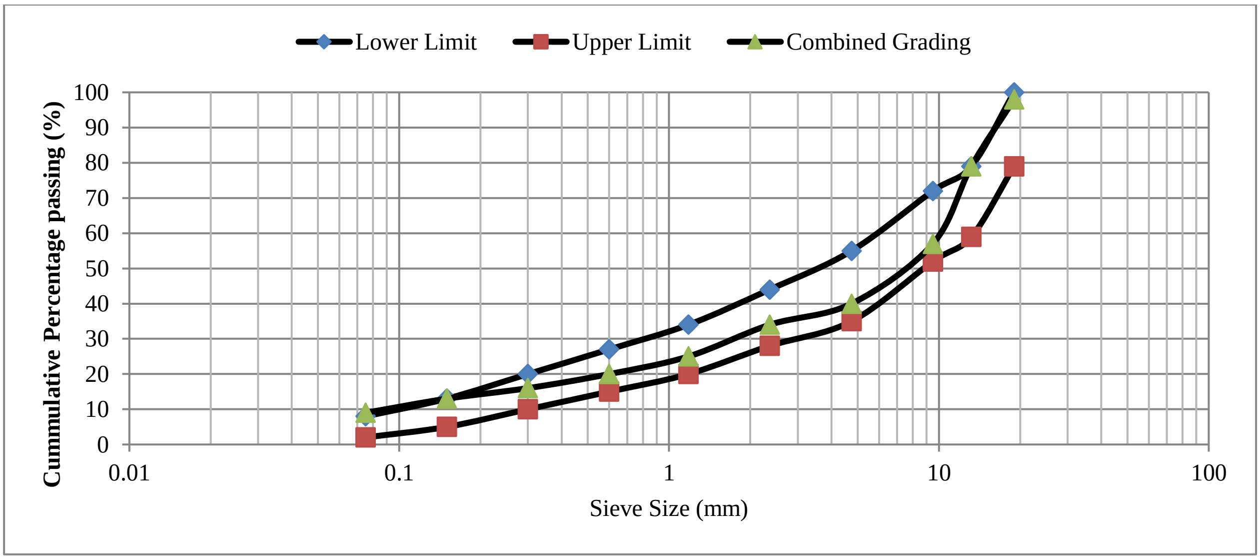


Figure 5.7 Shows the Gradation That Was Decided Upon and Its Limits for BC Mix.

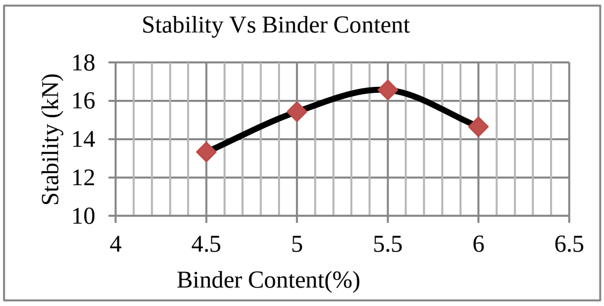
5.9 Finding Out What the Optimum Binder Content (OBC)

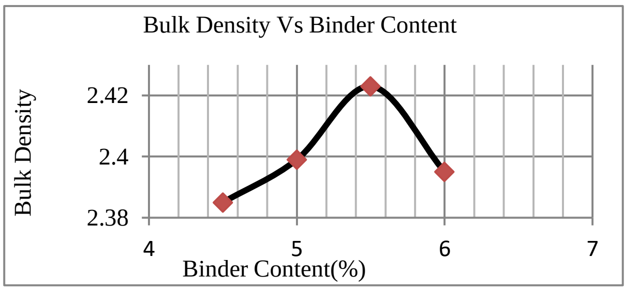
Marshall samples were treated with several concentrations of VG-30 bitumen in order to determine the OBC. The volumetric parameters of BC mixed with VG-30 Bitumen were then determined by means of the aforementioned equations and recorded in Table 5.8

Table 5.8 displays the test findings in graphical form. After weighing all of these factors, it was decided that binders should make up 5.4% of aggregates.

Table 5.8 Volume and Mechanical Properties of LPMBC after Addition of Fly Ash

Aggregate Binder Content (%)	Bulk Density, gm/cc	Stability (kN)	Flow Value (mm)	Air Voids, %	Mineral aggregate voids (VMA)	% Volume of Bitumen Used to Fill Vacancies
4.5	2.385	13.32	2.22	5.54	15.01	63.07
5.0	2.399	15.43	2.65	4.84	14.96	67.65
5.5	2.423	16.56	2.98	3.04	14.56	79.12
6.0	2.395	14.65	3.11	3.23	16.00	79.79





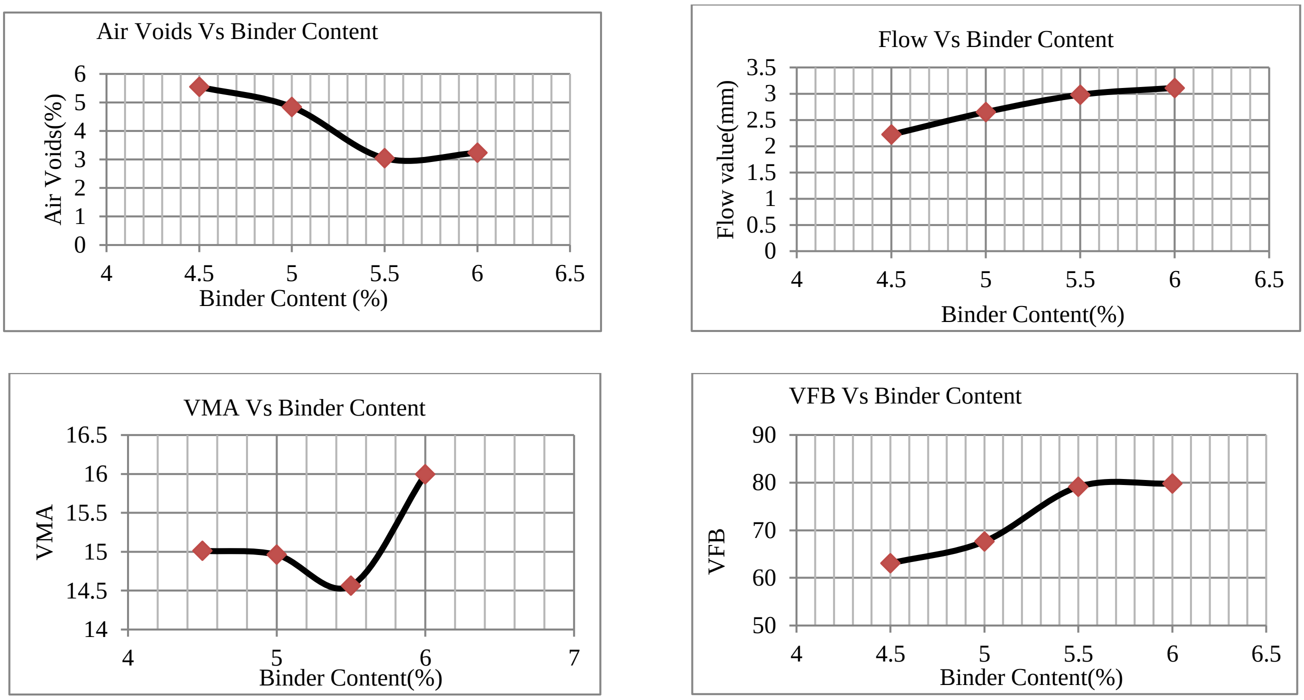


Figure 5.8 Properties of mix with respect to binder content

From the above results, optimum binder content summarized in the table as given below:

Table 5.9. Test results of Optimum binder content

Mix Type (Bituminous concrete)	Optimum Binder content (%)	
	Binder Type	
	VG-30	LPMB Mix
BC mix with Fly ash	5.2	5.4
BC mix with Lime	5.1	5.3

The results of the experiments indicate that a smaller proportion of binder is preferable when making conventional BC mixes. The Optimal Binder Content for Conventional and Modified Mixes Characterization.

Marshall Stability and Retained Marshall Stability values for four different combinations are compared in Table 5.9. Extensive worldwide laboratory testing of bituminous mixes for durability and performance is routinely performed. Several tests, such as a moisture susceptibility test, a beam fatigue test, and a thermal shock test, were conducted as part of this probe. The indirect tensile strength test, the resilient modulus test, the creep test, and the large wheel tracking test (Rutting experiments), were carried out. The methodology of the test, as well as the findings, will be discussed in the following sections. In the following sections, both the testing technique for each of these tests as well as the findings will be discussed. Due to the fact that this study looked at six distinct combinations, in order to maintain coherence and to make the evaluation of the findings more straightforward.

6.0 Results & Discussions:

The following material discusses the findings from a variety of tests. The aggregate's physical characteristics fall within the range outlined in MoRT&H for Marshall Mix design, guaranteeing its continued usage in bituminous mix production. All the specifications outlined in IS 73-2013 were satisfied by VG-30 bitumen. Except for elastic recovery, LPMB complied with the most of the requirements outlined in IRC SP-53-2010. According to IRC SP-53-2010, the Dynamic Shear Rheometer (DSR) test on unaged VG-30 and LPMB revealed that bitumen fails at 76°C and 78°C, respectively, under equivalent test conditions.

Marshall Mix stability and indirect tensile strength values improved when a little amount of liquid polymer was added to the modified binder. The maintained stability of samples comprising VG-30 and lime was found to be 88.56%, whereas samples prepared with liquid polymer were found to be 90.32%.

The tensile strength ratio for bituminous mix created with VG-30 and lime as a filler was found to be 86.51%, while the same attribute for mix prepared with lime and liquid polymer modified binder was found to be higher, at 91.12%. This indicates a 5.61% improvement in TSR values. Using fly ash instead of lime enhanced Marshall stability, maintained stability, indirect tensile strength, and tensile strength ratio.

7.0 Conclusions:

The following conclusions are drawn based on laboratory test results and data analysis. The BC combination with LPMB had higher tensile strength ratios than the mix without polymer. Incorporating liquid polymer modified bitumen improved moisture resistance. Additionally, the BC mixture with liquid polymer was more stable than the BC mix with VG-30 bitumen. The elastic recovery of LPMB did not meet the 2010 IRC SP-53 standards. However, $G^*/\sin\delta$ for LPMB is 2 °C higher than VG-30.

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