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EFFECT OF BINDER CONTENT ON VOLUMETRIC PROPERTIES OF ASPHALT MIXES

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ABSTRACT

The aim of this study is to examine the effect of changing of Asphalt content on the volumetric properties of Asphalt concrete Mix. Volumetric properties of mix include VFA (Voids filled with aggregates), VMA (voids in mineral aggregate), VTM (voids in total mix), F/A ratio (fine/asphalt ratio) and simply the air voids in the mix. Marshal Mix design samples are prepared using the National Highway Authority (NHA) specifications for aggregates and using different binder content percentages of 3.5%, 4.0%, 4.5%, 5% and 5.50% respectively for the Grade 60/70 Asphalt. Effect of changes in binder content was plotted against the stability and flow values to investigate it. These samples are further tested to collect different data for analysis purpose such as specific gravity, etc. Results showed that the binder content is a sensitive parameter which affects the volumetric properties of bitumen. Maximum stability is only reached at the optimum binder content value which is obtained after the mix design.

1. INTRODUCTION

Economic development of a country is highly dependent upon its road infrastructure. So every country spent a significant amount of its budget on the development of road infrastructure. Pakistan has a very wide road infrastructure, starting from the Northern areas to the shore of Arabian Sea in the south. Geographical location of Pakistan on the globe has enhanced the importance of its road network because many countries are interested in using the roads of Pakistan for trade purposes specially China and the land locked countries of Central Asia are highly interested in this road network. The behavior of the bituminous mixture depends upon

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various factors and one of them is the percentage of binder content. If the binder content in the mixture is more it will lead to the bleeding of the pavement surface and early deformation problems of rutting. But the binder content below the optimum will not provide sufficient coating of the aggregate particles and this will result in the loss of bond between the aggregates, ultimately resulting in the formation of pot holes in the pavements so, it is important to determine the optimum binder content of each mix. Improper thickness and bituminous mix design accelerate the rate of deterioration of asphalt pavement structures. Socio-economic development is greatly affected by the deterioration of the roads, as a huge amount of budget has to be spent for their maintenance and rehabilitation. Common forms of failure of asphalt pavements are rutting and pothole formation, which causes the permanent deformation in the top asphaltic layer. The performance of hot mix asphalt (HMA) pavements depends upon the properties of HMA mixes of which they are constructed. The properties of HMA mixes depend upon their volumetric properties. In Marshall Mix deign method asphalt binder content is one of the most important parameter which controls the volumetric properties of asphalt mix. The accurate determination of suitable proportions of asphalt binder in hot mix asphalt (HMA) is critical to control is volumetric properties and performance. This research is aimed to characterize the effect of varied binder content on the volumetric properties of hot mix asphalt.

2. OBJECTIVES

1. To check the sensitivity of volumetric properties and performance of asphalt mixes against varied binder content.
2. To check the effect of change of volumetric properties on the performance of hot mix asphalt (HMA) pavements due to change in binder content.

3. RESEARCH METHODOLOGY

To obtain the objective of this project, the following methodology was adopted.

1. Literature Review.
2. Procurement of locally available asphalt binder and aggregate samples.
3. Design of HMA mixes using Marshall Method at four compaction levels.

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4. Determination of volumetric properties of HMA mixes at four compaction levels.

5. Analysis of Results.

Literature review will be a continuous process for the duration of the work carried out in this research study. Major objective of the literature review will be the identification of different properties of Asphalt binder, aggregates and HMA mixes. Study about Marshall Stability and flow testing procedure and also the study of relationship between binder content and volumetric properties of HMA.

4. LABORATORY TESTING

In order to accomplish the objectives of this study, first we have prepared Marshall mix design samples at varying binder contents (3.5%-5.5%) and determined the stability and flow values for every sample at varying moisture content. Than we proceed further for measuring the bulk specific gravity and maximum specific gravity of the HMA mix.

4.1 Testing Matrix

National Highway Authority Pakistan's fine wearing course is used

Binder type = 1

Compaction levels = 4

Binder content = 5

Replicates = 3

Total number of samples = 1×5×4×3 = 60

4.2 Marshal Stability and Flow Test

In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. There are two major features of the Marshall method of mix design. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow values the deformation that the test specimen undergoes during loading up to the maximum load.

4.3 Test Apparatus

1. Mould assembly

2. Sample extractor

3. Compaction pedestal and hammer

4. Loading machine

5. Flow meter

6. Water bath

7. Thermometer

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4.4 Test Procedure

In the Marshall method of mix design three compacted samples are prepared for each binder content value. At least four binder contents are to be tested to get the optimum binder content. The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfil the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5mm approximately. 1200gm of aggregates and filler are required to produce the desired thickness. The aggregates are heated to a temperature of 175°to 190°C the compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen is heated to a temperature of 121°C to 138°C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. The mix is placed in a mould and compacted with number of blows specified. The sample is taken out of the mould after few minutes using sample extractor.

After preparing the samples test the samples for stability and flow values in Marshall Stability and flow apparatus. In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60° ±1°C for a period of 30 minutes. It is then placed in the Marshall Stability testing machine and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in KN (that causes failure of the specimen) is taken as Marshall Stability**.** The total amount of deformation that occurs at maximum load is recorded as Flow Value.

4.5 Bulk Specific Gravity of HMA

The bulk specific gravity test is used to determine the specific gravity of a compacted HMA sample by determining the ratio of its weight to the weight of an equal volume of water. Specific gravity is defined as the ratio of the mass of a volume of a material at a stated temperature to the mass of the same volume of distilled water at a stated temperature. Specific gravity has a variety of important applications in hot mix asphalt engineering. Perhaps most importantly specific gravity is used in determination of the percent air voids. The Standard Method of Test for Bulk Specific Gravity of Compacted Bituminous mixtures Using Saturated Surface-Dry Specimens AASHTO T- 166 states that the method is not applicable to specimens with a water absorption of greater than two percent.

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Determine the Bulk Specific Gravity of the compacted cores in accordance with AASHTO T-166 Method as follows:

1. Dry the specimen to a constant mass.
2. Cool the specimen to room temperature at 77 ± 9 °F (25 ± 5 °C), and record the dry mass **A**.
3. Immerse each specimen in water at 77 ± 3 °F (25 ± 1 °C) for 4 ± 1 minute and record the immersed mass, **C**.
4. Remove the specimen from the water, quickly damp dry the specimen by blotting with a damp towel as quickly as possible, and determine the surface-dry mass, **B**.
5. Calculate the Bulk Specific Gravity of each specimen using the following equation:

Bulk Specific Gravity (BSG) of Core = $\frac{A}{B-C}$

Where: A = Weight of Core in Air

B = SSD Weight of Core in Air

C = Weight of Core in Water

6. Calculate the average Bulk Specific Gravity of the mix (G_{mb}) using the following equation:

$$G_{mb} = \frac{BSG\ speciemn\ 1 + BSG\ specimen\ 2 + BSG\ specimen\ 3}{3}$$

4.6 Maximum Specific Gravity

The volumetric properties of HMA are required to be controlled during design and production to produce durable pavements. A test to measure the volume of a mixture with all the air voids removed is needed to measure this durability. The maximum specific gravity (G_{mm}) of HMA is the ratio of the weight of the loose sample to the weight of an equal volume of water at the standard temperature of 77°F (25°C).

Following test procedure is adopted in the laboratory during the testing in accordance with ASTM standards.

1. Once the sample is dry and while it is still warm, separate the particles of the sample of paving mixture by hand, taking care to avoid fracturing the aggregates. Cool the sample to room temperature. Place the sample directly into the volumetric flask or bowl. Weigh the flask or bowl with the sample and designate the net mass (mass of sample only) as “A”

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2. Add sufficient water at a temperature of approximately 25°C (77°F) to cover the sample completely. Place the cover (bowls) or stopper (flask) on the container.

3. Place the container with the sample and water on mechanical agitation device (or which one available) and anchor it to the surface of the device. Start the agitation and immediately begin to remove air trapped in the sample by gradually increasing the vacuum pressure. The vacuum should be achieved within 2 min.

4. Once the vacuum is achieved, continue the vacuum and agitation for 13-17 min.

Gradually release vacuum pressure. Slowly fill the flask with water taking care not to introduce air into the sample. Determine the mass of the flask, plate, and its contents completely filled with water. Designate this mass as E.

5. Empty the flask and fill the flask with water only and record the mass of flask and water as "D".

6. Finally calculate the theoretical maximum specific gravity by using the following equation $G_{mm} = \frac{A}{A+D-E}$

Where,

A = mass of dry sample in air, g,

D = mass of lid and bowl with water at 25°C (77°F), g,

E = mass of lid, bowl, sample, and water at 25°C (77°F), g

5. RESULTS

Test performed with varying percentages of asphalt binder content ranging from 3.5% - 5.5% for the following compactive efforts:-

1. 25 blows (presented in Table 1 and 2)
2. 35blows (presented in Table 3 and 4)
3. 50blows (presented in Table 4 and 5)
4. 75blows (presented in Table 5 and 6)

For each compactive effort graphs depicting following relationships were plotted:-

1. Percentage binder content vs Voids in Mineral Aggregates (VMA).
2. Percentage binder content vs Voids Filled with Asphalt (VFA).
3. Percentage binder content vs Voids in Total Mix (VTM).
4. Percentage binder content vs specific gravity.

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5. Percentage binder content vs stability.
6. Percentage binder content vs flow.

6. CONCLUSIONS

After performing and analyzing results obtained from the testing performed were closely observed and the following conclusions were made.

1. Binder content is a sensitive parameter and it affects the volumetric properties of HMA.
2. Maximum Stability is achieved at optimum binder content which achieved after the complete Mix design.
3. Higher binder content in a mix reduces the resistance to compaction.
4. The binder content cannot be too high because it would result in the instability of the bituminous pavement.
5. The resistance to deformation of bituminous pavement under traffic load is reduced by the inclusion of excessive binder content.
6. For a given mixture, as binder content increases, air voids decreases and vice versa.
7. Excessive binder content is HMA leads to rutting, wash boarding, flushing or bleeding.
8. Lower binder content leads to dryness or raveling.
9. Lower binder content will result in thin film coating on the particles which will ultimately lead to early aging of the mix.
10. An open graded HMA with high binder content is generally more flexible than dense graded, low binder content HMA.
11. Air voids (related to binder content) and binder viscosity has a significant effect on fatigue resistance. Lower asphalt binder content will lead to fatigue cracking.
12. Since Asphalt binder content affects HMA mixture performance in the areas of stiffness, strength, durability, fatigue life, raveling, rutting and moisture damage it is important in HMA pavement forensic investigations and HMA research.

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13. Quantitative determination of the asphalt binder content of HMA mixtures is necessary for quality assurance, quality control, specification acceptance, and mixture evaluation studies.

14. HMA that has too much asphalt binder can experience problems such as bleeding, lowered skid resistance, and lowered resistance to permanent deformation (rutting and shoving).

15. HMA that has too little asphalt binder can have lowered fatigue resistance and problems with raveling and stripping.

16. Based on the grading of aggregates, as the number of fine particles increases, the amount of bituminous binder needed to coat these surfaces also increase. Conversely, because coarser HMA has less total aggregate surface area, the aggregates require less binder. This is why surface HMA requires more binder than base HMA.

7. FUTURE WORK

1. For comprehensive and explanatory results different binder contents and aggregate gradations should be tested and subsequent analysis should be done on that.

2. Optimum binder content should be analyzed and effect of compactive effort on optimum binder content should be closely observed.

3. In recent years use of polymer modified asphalt is increasing day by day, so modified asphalt should also be analyzed in addition to regular asphalt binders and their effect on the volumetric properties of HMA mix should be observed.

4. Samples should be prepared using both, the hammer compactor and gyratory compactor and then analysis for both of them should be done for comparison purposes.

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LIST OF TABLES

Table 1: Stability, Flow and Specific Gravities of Marshall plugs for 25 blows

Compactive Effort	Binder Content	Sample	Flow	Stability	Flow	Stability	Corrected Stability	Average Flow	Average Stability	G_{mb}	Avg.G_{mb}
			Mm	N	Mm	N		Mm	N		
25 Blows	3.50%	1	145	405	14.5	5001	4301	16.6	4743	2.290	2.304
		2	165	510	16.5	6265	5576			2.306	
		3	185	410	18.5	5062	4353			2.314	
	4.00%	1	160	310	16	3858	3318	16.2	4077	2.318	2.299
		2	135	372	13.5	4604	3960			2.286	
		3	190	452	19	5567	4955			2.292	
	4.50%	1	175	542	17.5	6651	6185	15.5	5718	2.325	2.338
		2	160	545	16	6687	5951			2.343	
		3	200	458	20	5639	5019			2.347	
	5%	1	110	350	11	4339	4166	12	4630	2.285	2.296
		2	110	460	11	5664	5267			2.310	
		3	140	420	14	5182	4457			2.294	
	5.50%	1	130	455	13	5603	4987	15	5750	2.346	2.361
		2	135	495	13.5	6085	5841			2.359	
		3	175	563	17.5	6903	6420			2.380	

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Table 2: VTM, VMA and VFA for Marshall Plugs for 25 blows

Compactive Effort	Binder Content	Sample	A	D	E	G_{mm}	$G_{mm(avg)}$	VTM	VMA	VFA
25 Blows	3.50%	1	1200	10349	11083	2.575	2.609	11.71	17.971	17.971
		2	1200	10349	11095	2.643				
	4.00%	1	1200	10349	11084	2.581	2.559	10.173	18.576	18.576
		2	1200	10349	11076	2.537				
	4.50%	1	1200	10349	11085	2.586	2.530	7.585	17.598	17.598
		2	1200	10349	11064	2.474				
	5.00%	1	1200	10349	11028	2.303	2.317	0.886	19.507	19.507
		2	1200	10349	11034	2.330				
	5.50%	1	1200	10349	11023	2.281	2.383	0.9	17.653	17.653
		2	1200	10349	11066	2.484				

Table 3: Stability, Flow and Specific gravities of Marshall plugs for 35 blow

Compactive Effort	Binder Content	Sample	Flow	Stability	Flow	Stability	Corrected Stability	Average Flow	Average Stability	G_{mb}	$G_{mb(avg)}$
			Mm	N	mm	N		Mm	N		
35 Blows	3.50%	1	150	518	15	6362	5916	14.0	5753	2.372	2.369
		2	155	425	15.5	5242	4666			2.366	
		3	115	586	11.5	7180	6678			2.370	
	4.00%	1	120	555	12	6807	6331	13.2	5893	2.348	2.346
		2	170	642	17	7854	7540			2.357	
		3	140	520	14	6386	5683			2.333	
	4.50%	1	120	433	12	5339	4965	12.8	5900	2.355	2.354
		2	130	535	13	6566	6304			2.354	

		3	135	564	13.5	6915	6431			2.353	
	5%	1	125	615	12.5	7529	7002	12.3	6209	2.380	2.365
		2	130	560	13	6867	6593			2.359	
		3	115	425	11.5	5242	5033			2.356	
	5.50%	1	135	582	13.5	7132	6847	12.7	6794	2.384	2.377
		2	145	630	14.5	7710	7710			2.385	
		3	100	510	10	6265	5827			2.361	

Table 4: VTM, VMA and VFA of Marshall Plugs for 35 Blows

Compactive Effort	Binder Content	Sample	A	D	E	G_{mm}	G_{mm}	VTM	VMA	VFA
35 Blows	3.50%	1	1200	10349	11078	2.548	2.653	10.7	16.863	36.545
		2	1200	10349	11114	2.759				
	4.00%	1	1200	10349	11100	2.673	2.674	12.27	16.895	27.375
		2	1200	10349	11100.5	2.676				
	4.50%	1	1200	10349	11061.5	2.462	2.490	5.459	17.044	67.974
		2	1200	10349	11072.5	2.518				
	5.00%	1	1200	10349	11054	2.424	2.500	5.386	17.092	68.491
		2	1200	10349	11083	2.575				
	5.50%	1	1200	10349	11056	2.434	2.475	3.952	17.109	76.900
		2	1200	10349	11072	2.516				

Table 5: Stability, Flow and Specific Gravities of Marshall plugs for 50 Blows

Compactive Effort	Binder Content	Sample	A	D	E	G_{mm}	G_{mm}	VTM	VMA	VFA
50 Blows	3.50%	1	1200	10349	11078	2.548	2.653	10.7	16.863	36.545
		2	1200	10349	11114	2.759				

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	4.00%	1	1200	10349	11100	2.673	2.674	12.27	16.895	27.375
		2	1200	10349	11100.5	2.676				
	4.50%	1	1200	10349	11061.5	2.462	2.490	5.459	17.044	67.974
		2	1200	10349	11072.5	2.518				
	5.00%	1	1200	10349	11054	2.424	2.500	5.386	17.092	68.491
		2	1200	10349	11083	2.575				
	5.50%	1	1200	10349	11056	2.434	2.475	3.952	17.109	76.900
		2	1200	10349	11072	2.516				

Table 6: VTM, VMA and VFA of Marshall plugs for 50 blows

Compactive Effort	Binder Content	Sample	A	D	E	G_{mm}	G_{mm}	VTM	VMA	VFA
50 Blows	3.50%	1	1200	10409	11130	2.505	2.480	3.816	15.074	74.682
		2	1200	10409	11120	2.454				
	4.00%	1	1200	10409	11110	2.405	2.455	2.605	15.299	82.970
		2	1200	10409	11130	2.505				
	4.50%	1	1200	10409	11130	2.505	2.467	3.379	15.994	78.876
		2	1200	10409	11115	2.429				
	5.00%	1	1200	10409	11117	2.439	2.428	2.317	16.859	86.256
		2	1200	10409	11112	2.417				
	5.50%	1	1200	10409	11120	2.454	2.449	0.525	17.723	97.040
		2	1200	10409	11118	2.444				

Table 7: Stability, Flows and Specific Gravities of Marshall Plugs for 75 Blows

Compactive Effort	Binder Content	Sample	Flow	Stability	Flow mm	Stability N	Corrected Stability	Average Flow	Average Stability	G_{mb}	$G_{mb(avg)}$
75 Blows	3.50%	1	150	650	15	7951	8269	15.3	8102	2.396	2.398

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		2	140	710	14	8673	9020			2.408	
		3	170	550	17	6747	7017			2.390	
	4.00%	1	140	640	14	7830	7517	15.7	7816	2.374	2.392
		2	150	620	15	7590	7286			2.387	
		3	180	680	18	8312	8644			2.415	
	4.50%	1	130	728	13	8890	8890	14.3	9394	2.413	2.426
		2	140	690	14	8432	8769			2.423	
		3	160	830	16	10117	10522			2.441	
	5%	1	110	800	11	9756	9366	12.2	9414	2.408	2.413
		2	130	680	13	8312	7979			2.397	
		3	125	860	12.5	10478	10898			2.433	
	5.50%	1	165	728	16.5	8890	8890	14.5	9898	2.430	2.440
		2	130	780	13	9515	9515			2.439	
		3	140	850	14	10358	11290			2.452	

Table 8: VTM, VMA and VFA of Marshall plugs for 75 blows

Compactive Effort	Binder Content	Sample	A	D	E	G_{mm}	G_{mm}	VTM	VMA	VFA
75 Blows	3.50%	1	1200	10349	11100	2.673	2.643	9.291	14.614	36.425
		2	1200	10349	11090	2.614				
	4.00%	1	1200	10409	11143	2.575	2.586	7.522	15.275	50.758
		2	1200	10409	11147	2.597				
	4.50%	1	1200	10409	11139	2.553	2.550	4.890	14.517	66.312
		2	1200	10409	11138	2.548				
	5.00%	1	1200	10409	11137	2.542	2.537	4.901	15.423	68.221
		2	1200	10409	11135	2.532				
	5.50%	1	1200	10349	11066	2.484	2.519	3.115	14.902	79.098

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		2	1200	10349	11079	2.553				

LIST OF FIGURES

5.1 Relationships

Stability vs. Binder Content

Graphs showing the relationship between stability and binder content for compactive efforts for 25, 35,50 and 75 blows are presented in Figures 1, 2, 3 and 4 respectively.

Figure 1: Stability vs. Binder Content at 25 Blows

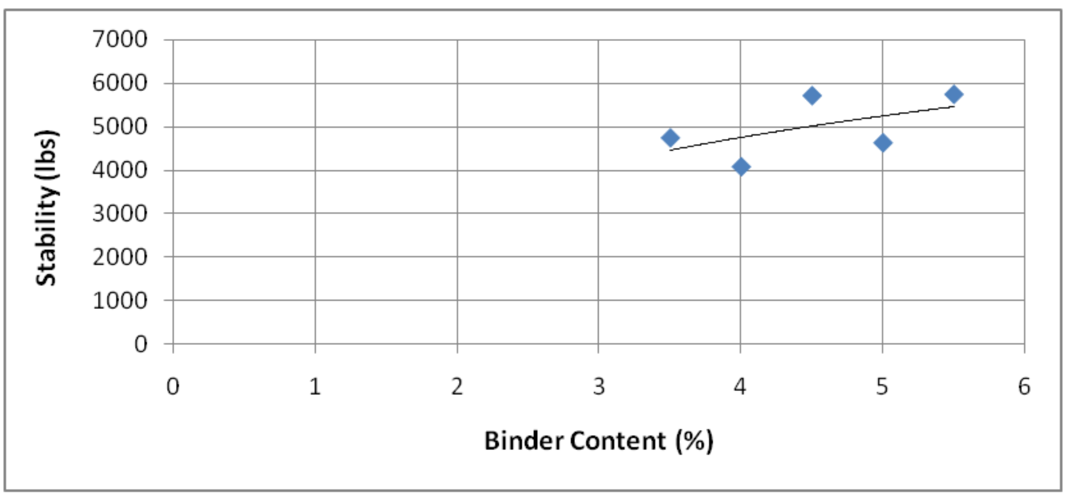

Figure 2: Stability vs. Binder Content at 35 Blows

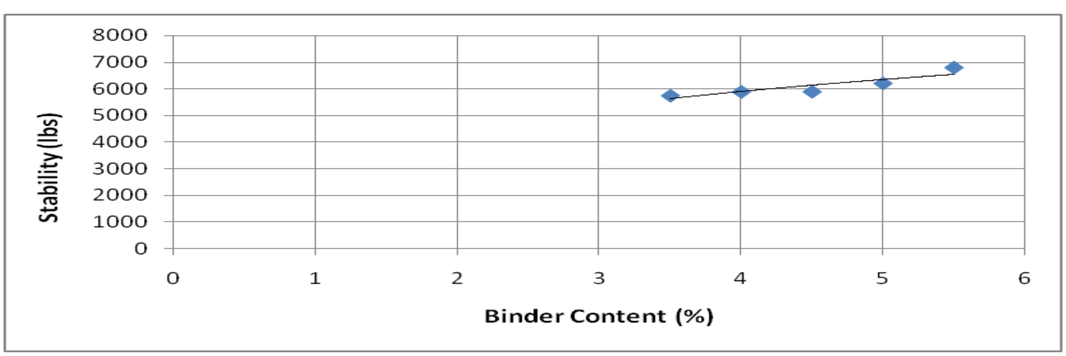

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Figure 3: Stability vs. Binder Content at 50 Blows

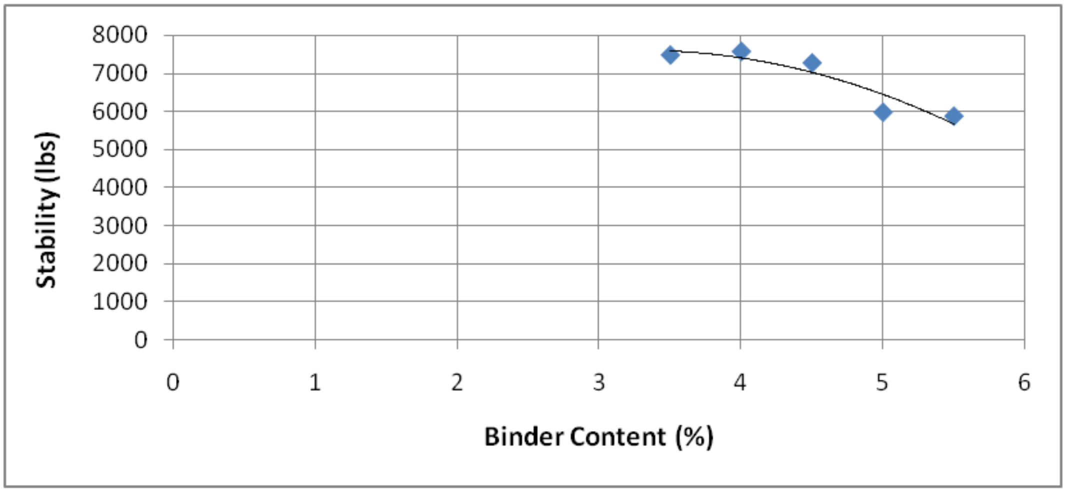
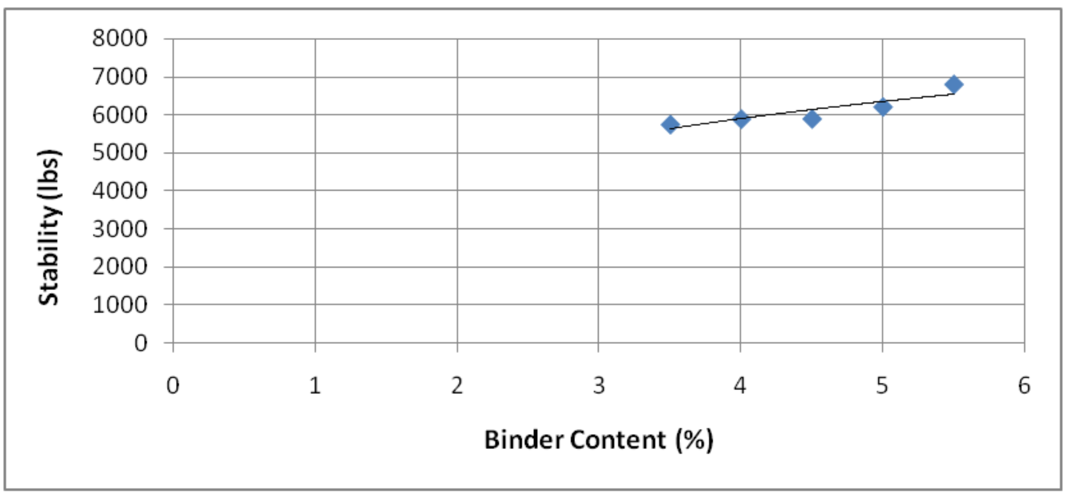


Figure 4: **Stability vs. Binder Content at 75 Blows**



Flow vs. Binder Content

Graphs showing the relationship between flow and binder content for different comp active efforts of 25, 35, 50 and 75 blows are presented in Figures 5, 6, 7 and 8 respectively.

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Figure 5: Flow vs. Binder Content at 25 Blows

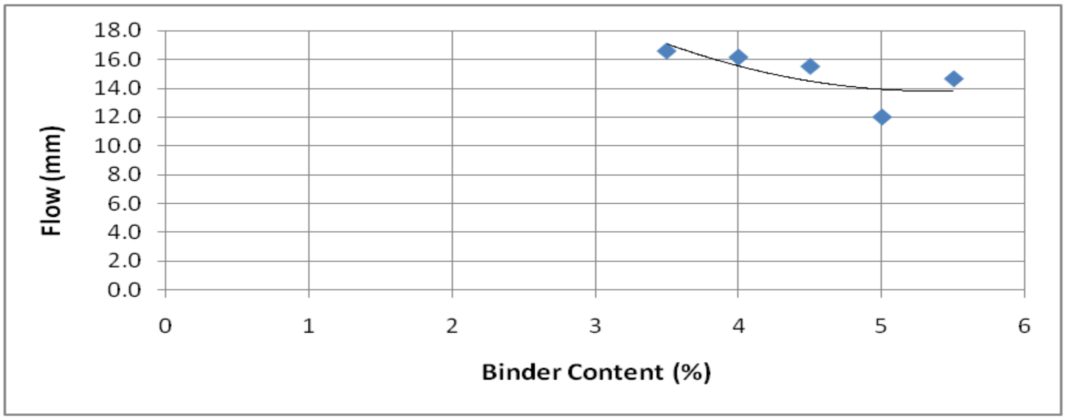

Figure 6: Flow vs. Binder Content at 35 Blows

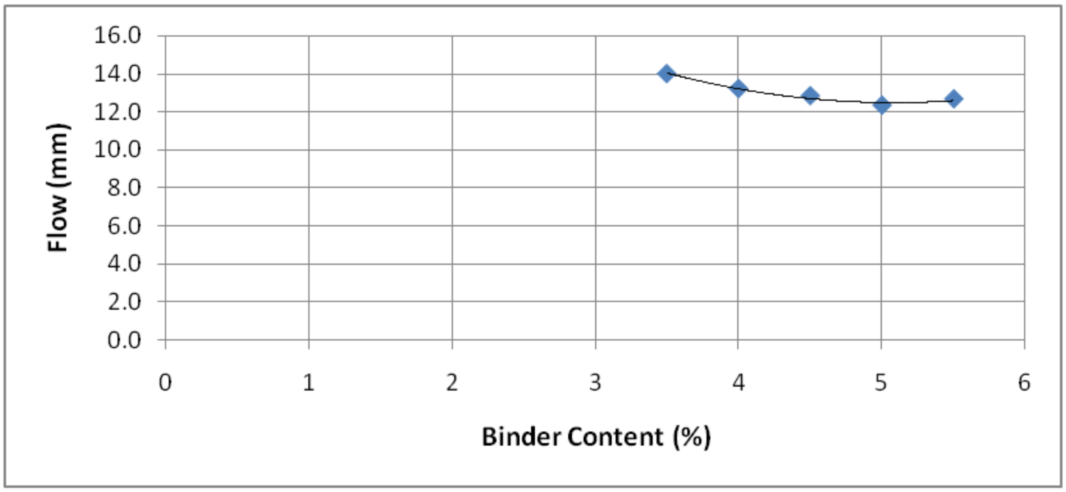

Figure 7: Flow vs. Binder Content at 50 Blows

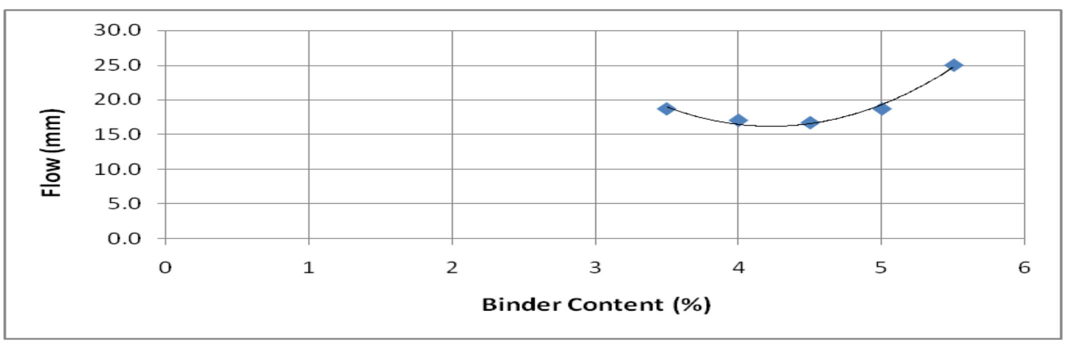

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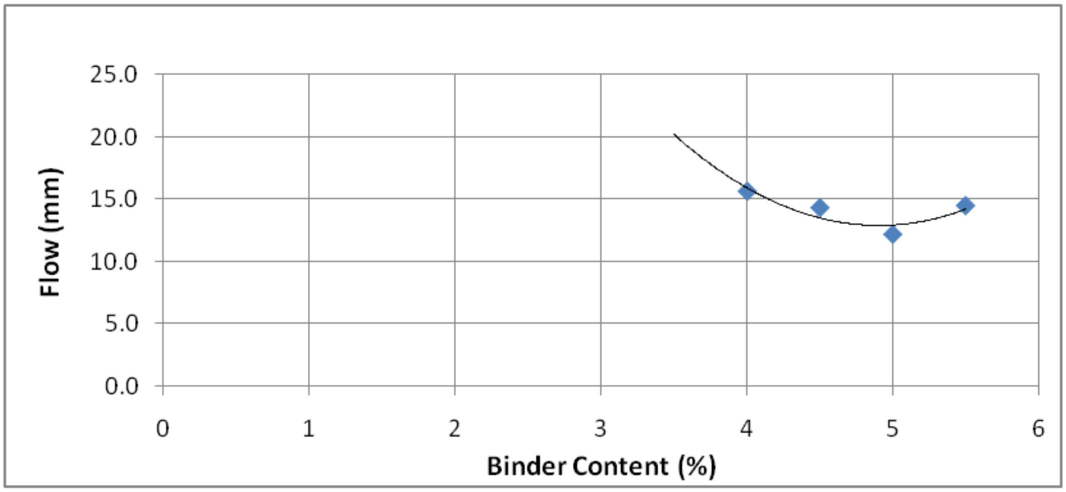
Figure 8: Flow vs. Binder Content at 75 Blows



VMA vs %binder content

Figures 9, 10, 11 and 12 present the relationship between VMA and binder content at compactive efforts of 25, 35, 50 and 75 blows respectively.

Figure 9: VMA vs. Binder Content at 25 Blows

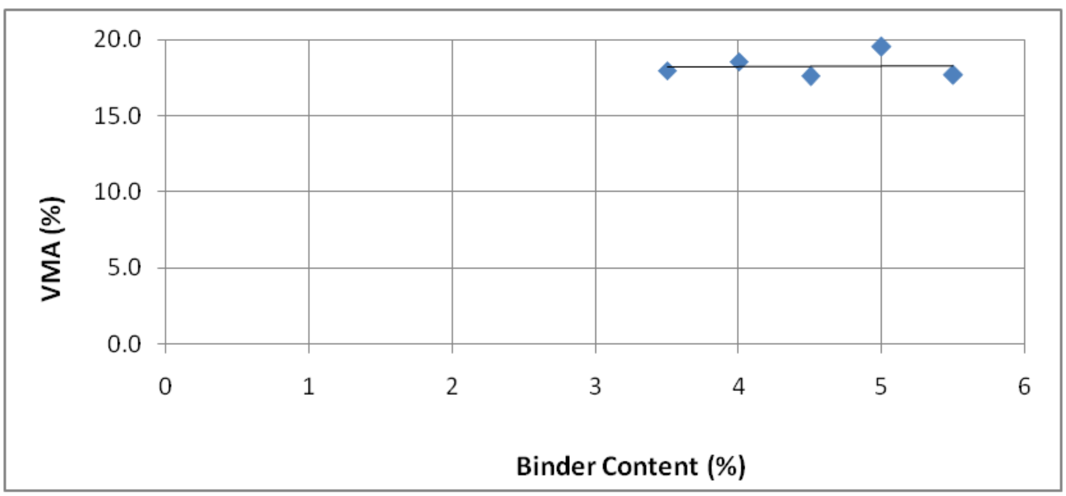


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Figure 10: VMA vs. Binder Content 35 Blows

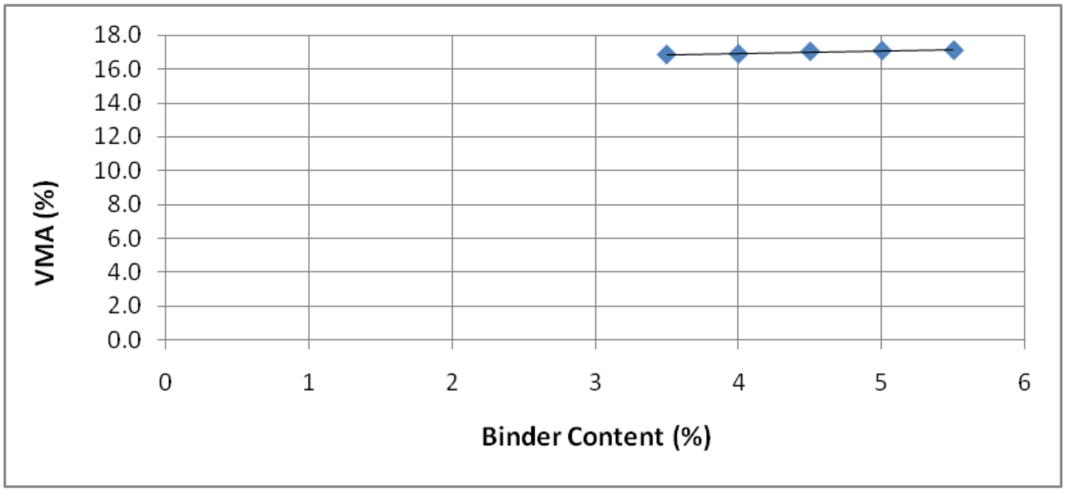


Figure 11: VMA vs. Binder Content at 50 Blows

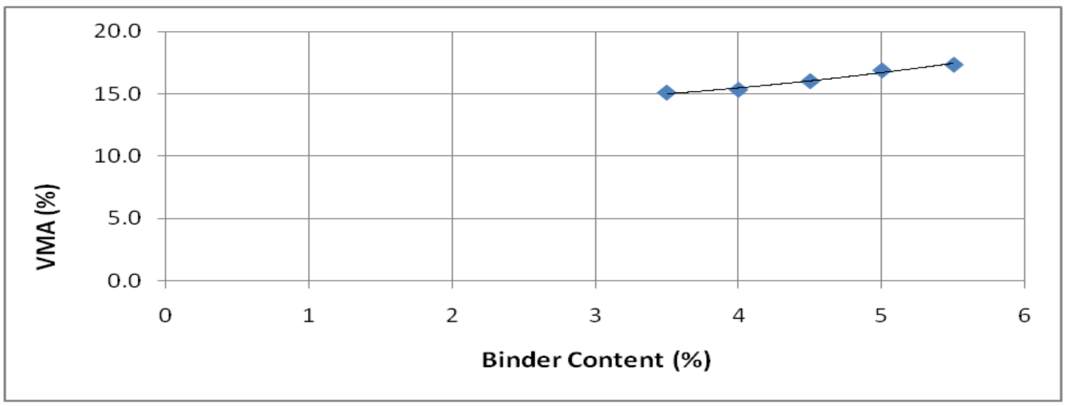
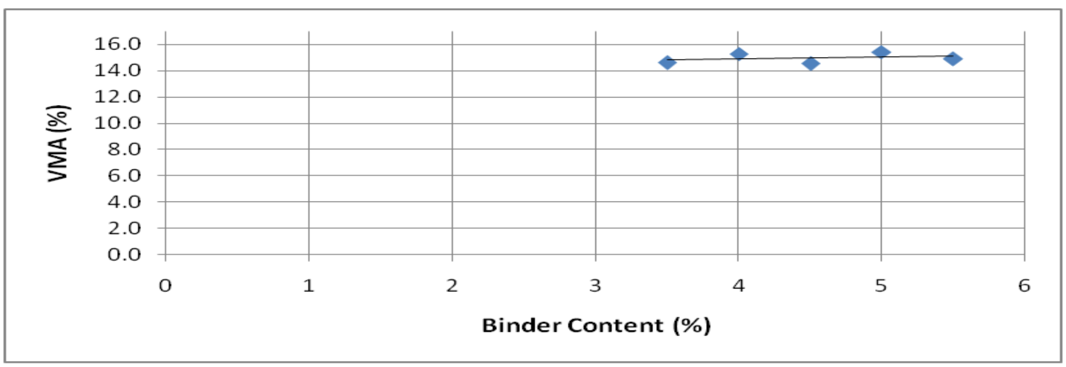


Figure 12: VMA vs. Binder Content at 75 Blows



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VTM vs % binder content

Figures 13, 14, 15 and 16 given below presents the relationship between VTM and binder content at compactive efforts of 25, 35, 50 and 75 blows.

Figure 13: VTM vs. Binder Content at 25 Blows

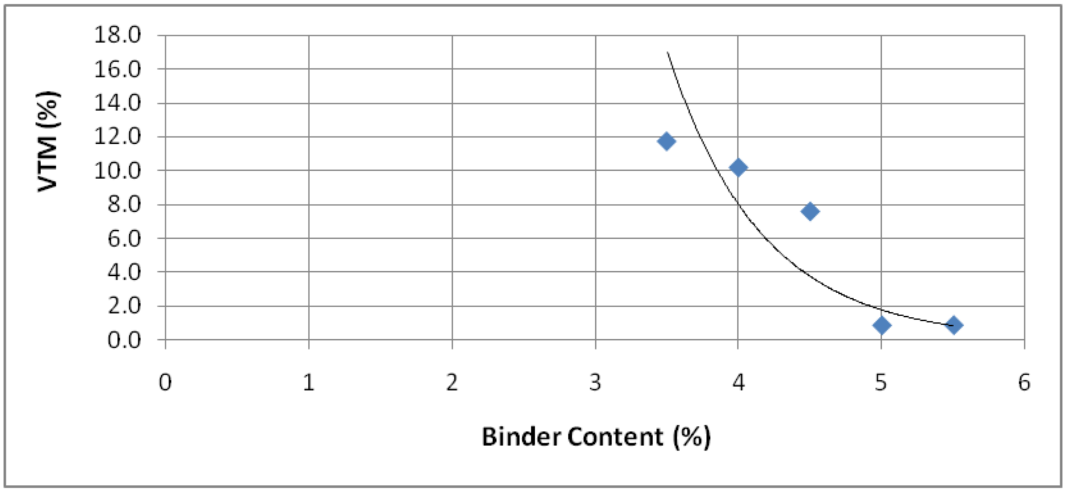

Figure 14: VTM vs. Binder Content at 35 Blows

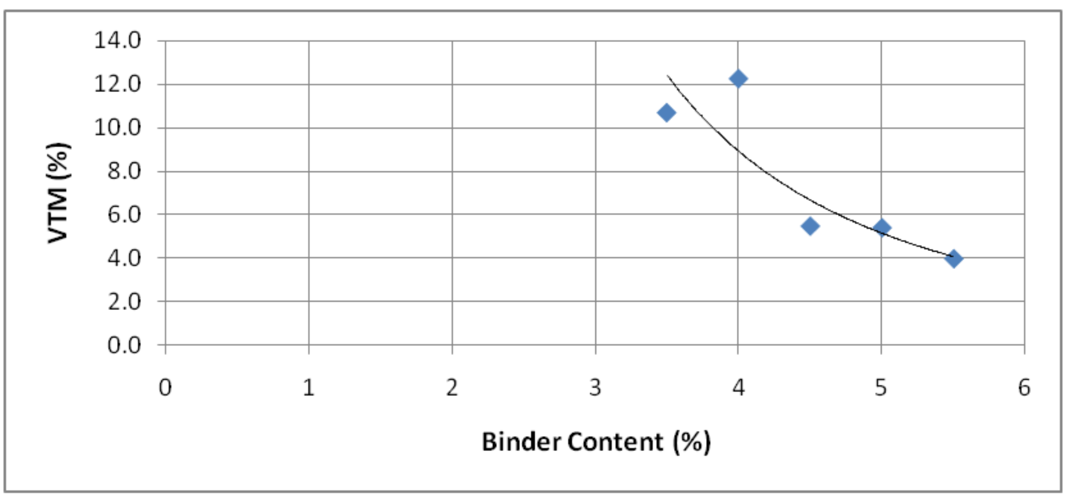

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Figure 15: VTM vs. Binder Content at 50 Blows

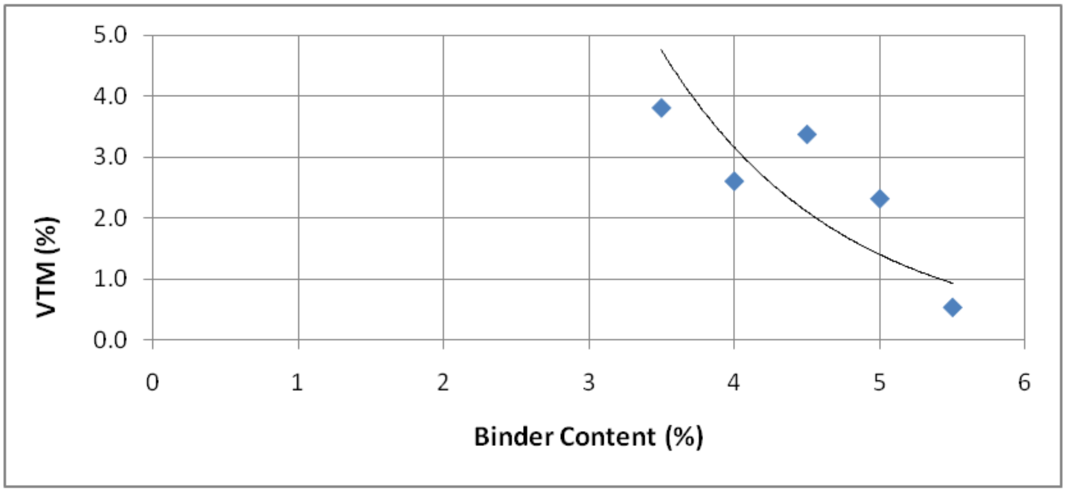
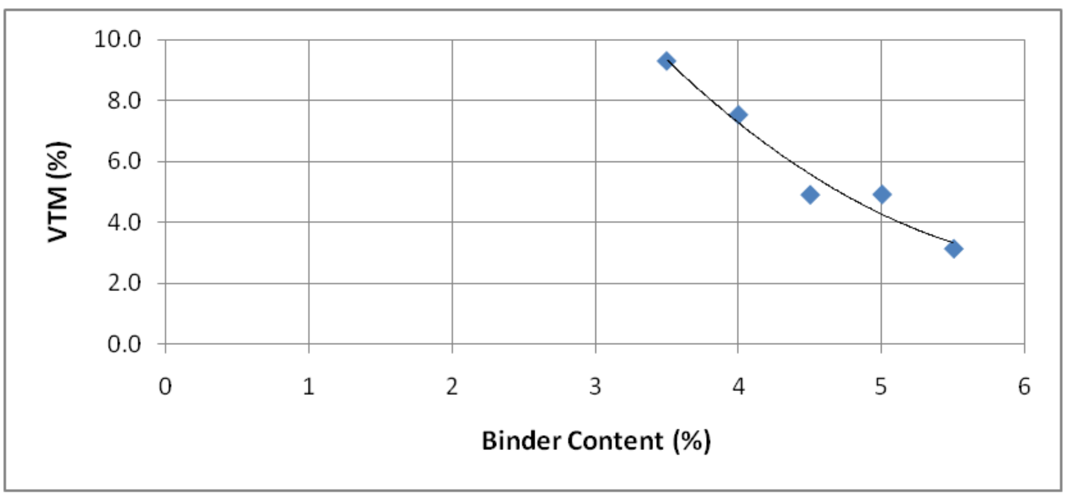


Figure 16: VTM vs. Binder Content at 75 Blows



VFA vs %binder content

Graphs depicting the relationship between VFA and binder content for different comp active efforts (for 25, 35, 50 and 75 blows) are presented in Figures 17, 18, 19 and 20 respectively.

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Figure 17: VFA vs. Binder Content at 25 Blows

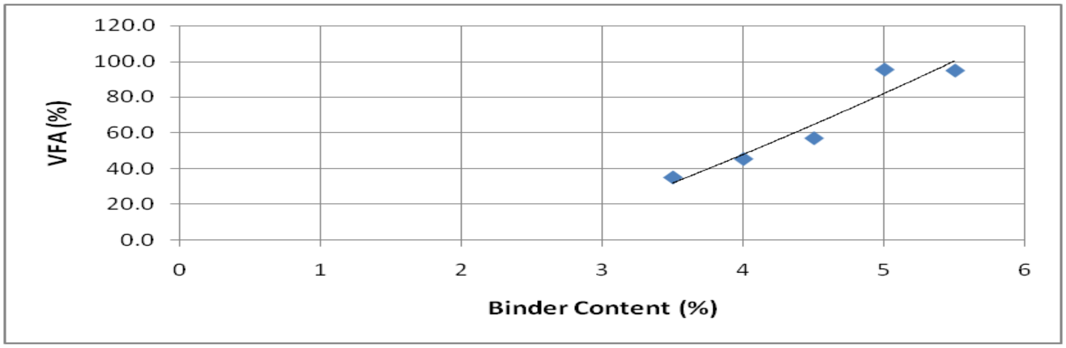

Figure 18: VFA vs. Binder Content at 35 Blows

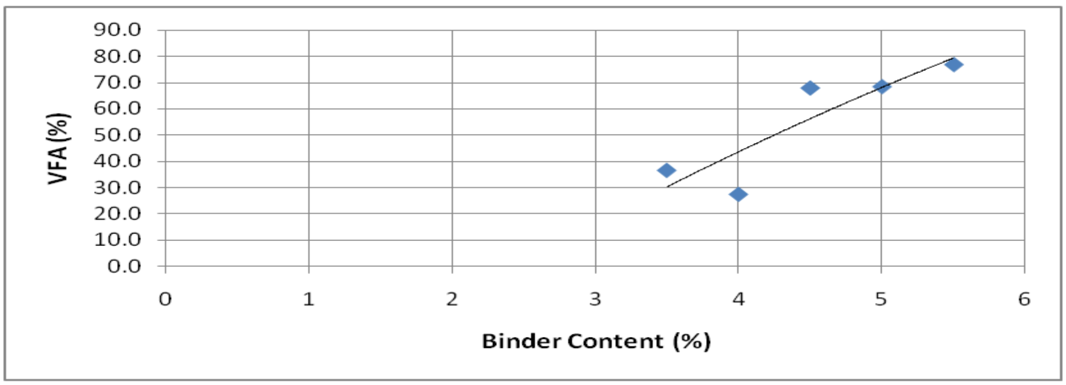

Figure 19: VFA vs. Binder Content at 50 Blows

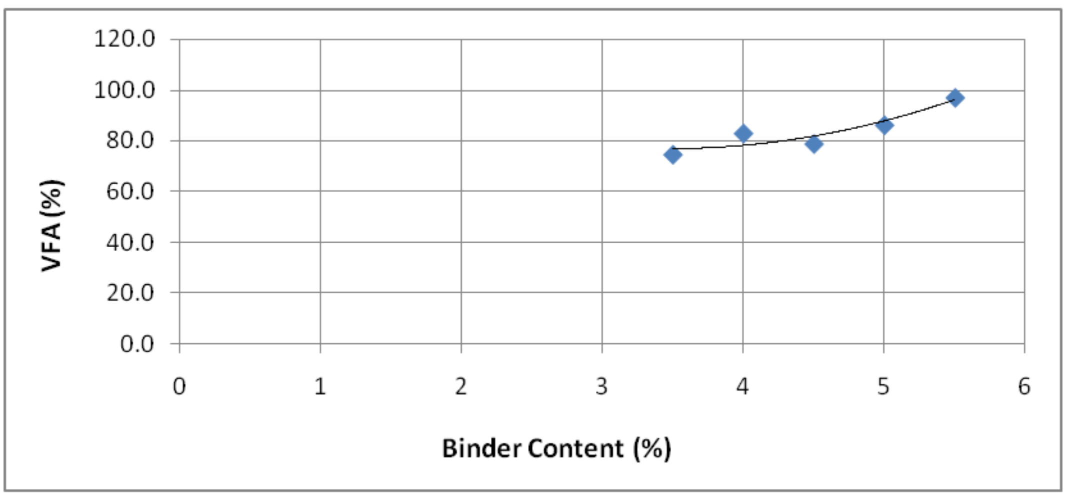

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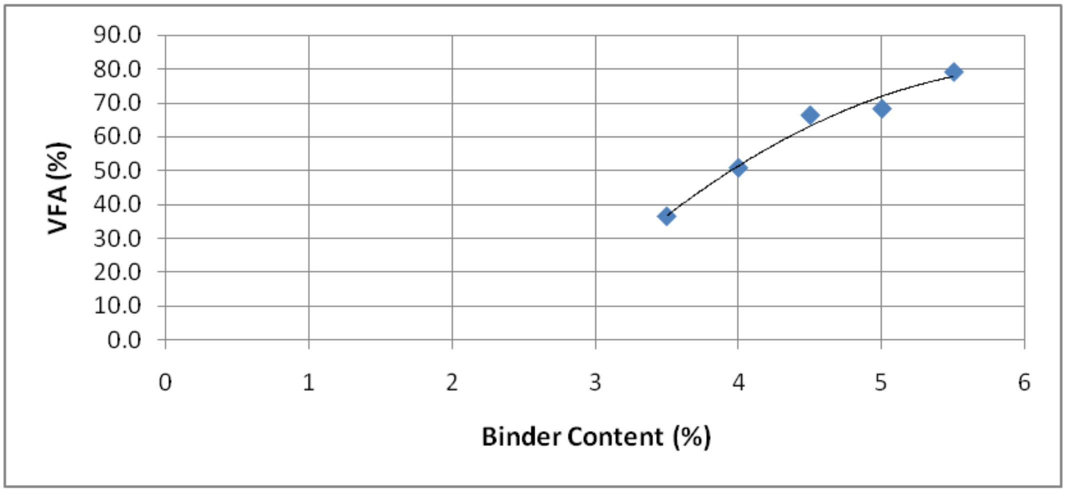
Figure 20: VFA vs. Binder Content at 75 Blows



Specific Gravity vs. Binder Content

Graphs depicting the relationship between specific gravity and binder content for various compactive efforts of 25, 35, 50 and 75 blows are presented in Figures 21, 22, 23 and 24 respectively.

Figure 21: Specific Gravity vs. Binder Content at 25 Blows

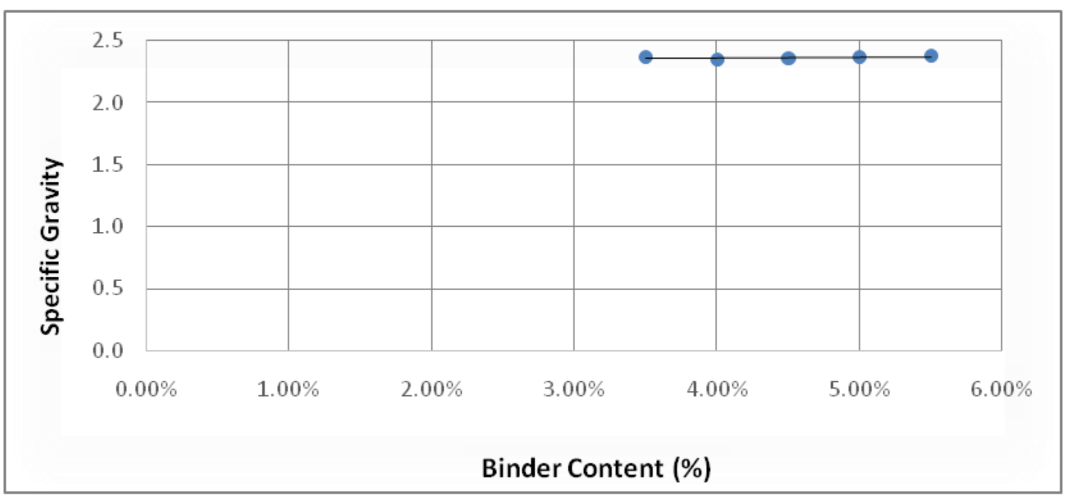


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Figure 22: Specific Gravity vs. Binder Content at 35 Blows

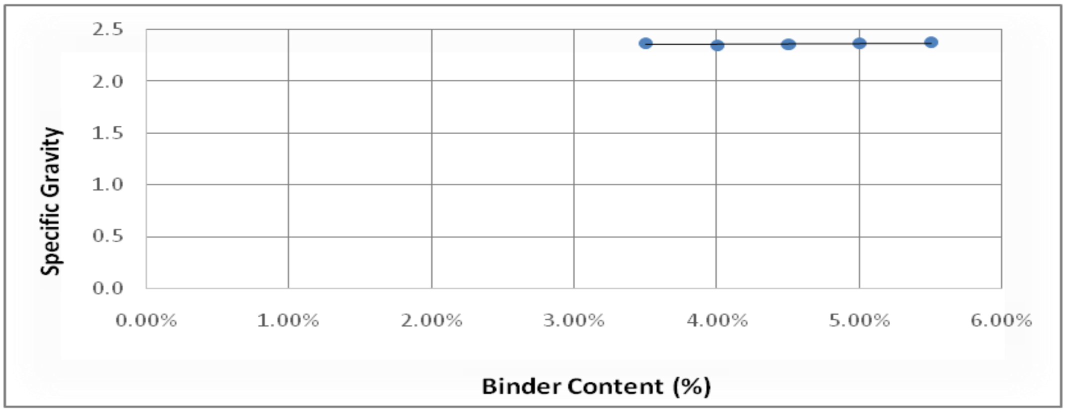

Figure 23: Specific Gravity vs. Binder Content at 50 Blows

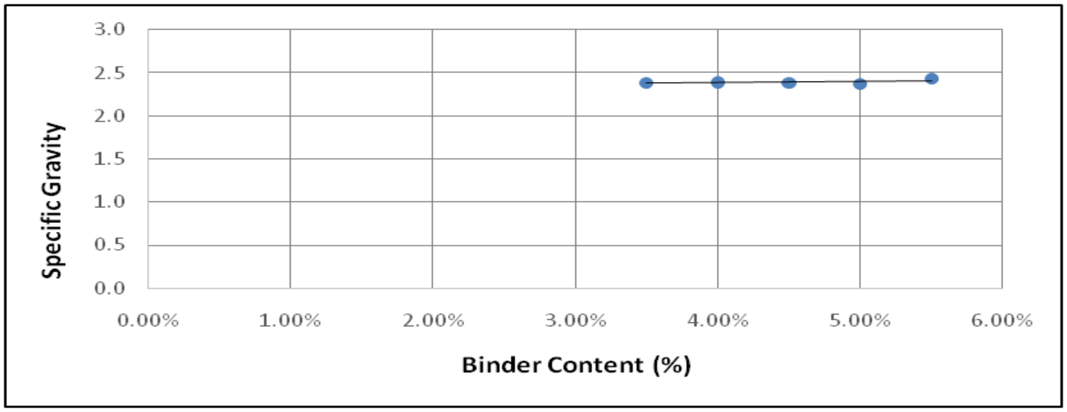

Figure 24: Specific Gravity vs. Binder Content at 75 Blows