EFFECT OF WASTE BONES AND GGBS AS MODIFIER FOR BITUMEN IN CONSTRUCTION OF FLEXIBLE PAVEMENT

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ABSTRACT

Bitumen has been modified for the past several decades using various additives, including synthetic polymers, various types of rubbers etc. This type of modification improves structural and engineering characteristics as a binder as well as its adhesion capability with the aggregate. In this experiment, bones and GGBS were chosenas additives. Generation of waste bones (from fertilizer factories) and GGBS (from various factory wastes) may be managed for using it as a modifier. They both have cementitious characteristics and are expected to provide good binding and waterproofing characteristics. Marshall Stability test was performed here to obtain various Marshall Parameters and to observe the changes from standard specifications. Also the effects of GGBS and bones were individually observed to have a better understandings. The bitumen content, bones and GGBS content were changed in suitable percentage to determine optimum bitumen content and average optimum bone and GGBS content. The design matrix was combined as such that only one parameter was variable and other parameters were fixed. The experiment result was that the stability and flow increased and decreased respectively to a considerable amount. Also, the air void percentage was within limits. VMA and VFB analysis suggest that adjustment is required as their percentage was below the minimum limit. Finally a design mix was achieved where all the parameters gave the best possible result for this experimental setup. It is concluded that the additives had some positive impact on bitumen and were able to enhance the mix design properties to some extent.

Keywords: *Waste bones, GGBS, Stability, Flow, Design-mix.*

1. INTRODUCTION

1.1 General

Progression of roads, structures, socio-economical standards, etc. define the condition of a country. To ensure the maintenance of this progress, the network system plays a vital role and the best network system is roadway network. A flexible pavement has different parts such as wearing course, base, subbase, subgrade etc. Bitumen is mainly used in wearing surfaces with aggregates and it is one of the most critical layers. As the wearing surface gets in direct contact with vehicles, it must be capable of withstanding abrasion, wear and tear due to heavy traffic load and also to prevent excessive entrance of water so that the layer beneath the surface is not highly damaged. Generally, bitumen is used worldwide for this wearing surface because of its binding and waterproofing quality. Bitumen production is economical, easily available, it can undergo recycling and recycled product can be used again for road construction, its physical and rheological properties bring versatilities to road construction and its low melting point makes it easy to work with. Also, bitumen is available in different grades suitable for different conditions which made it a popular material for road construction worldwide. Despite having such advantages, it also has drawbacks. The most common problems are various cracking, rutting and formation of potholes. One of the major causes of these problems is the faulty mix design of wearing courses. The susceptibility of bitumen to climate changes cannot be overlooked also. That's why maintaining bituminous pavements with utmost care is a challenge no matter where in the world because the traffic load is increasing in an alarming rate and frequent maintenance has become quite costly. The possible solution is to create a sustainable road network which is why various experiments are being conducted to modify bitumen to produce long-lasting effects.

Cliff Ellis et. al., (2004) researched on the effect of GGBS on bitumen. They had previously done some works related to this and those suggests that adding cementitious binder such as GGBS may enhance certain properties of bitumen emulsion mixtures. The results of their experiments showed that the inclusion of GGBS may enhance stiffness and strength development in high humidity conditions. S. Shahba et. al., (2017) investigated the effects of GGBS with SBS on the strength properties on bitumen. Modified bitumen and asphalt mixtures were evaluated based on the penetration test, Marshall Stability, etc. According to their results, the mixture of GGBS and SBS can be used to modify porous bitumen mixtures which will either improve or will not change their properties. This test also showed that using two additives simultaneously has strengthened bitumen mixture properties such as Marshall strength and uniaxial compression strength. A notable recent work which involved modifying bitumen with bone glue was done by Hashim Raza Rizviet et. al., (2014) which included mixing bone glue with bitumen mixture as waste bone glue has somewhat cementitious characteristics. In this study, a new kind of bitumen modifier derived from animal wastes, such as bones, hides, and flesh commonly known as Bone Glue was studied. This biomaterial which is a by-product of food and cattle industries is very readily available in developing countries. Their experiment showed a significant reduction of cost in bitumen mixture, a quality improvement of the mixture and also the whole process was quite environment-friendly which may be considered as a sustainable solution.

1.2 Objectives

- The main focus of this experiment is to observe the strengthening effect of both GGBS and waste bones as additives, as both of the materials has binding quality and they are waste products which make them easily accessible.
- To observe whether the improvement of Marshall stability of the bitumen mix in different mixing ratio is possible.
- To obtain optimum value of the bitumen mix design.
- To understand whether the experiment was able to provide results involving different parameters within standard or specified value.

2. METHODOLOGY

Marshall Method of mix design is the most popular method to determine the optimum bitumen content. Marshall Test method will be held for the performance analysis of Bones and GGBS mix with the standard bituminous mix. The Marshall test procedures have been standardized by the American Society for Testing and Materials (ASTM) and published as ASTM D1559. The method is applicable only to hot mixtures using penetration grades of asphalt cement and containing aggregates with a maximum size of 1 in. (25mm) or less (Paul H.Wright and Karen K. Dixon, 2004).This method best reproduces the field condition of wearing course. In this experiment medium type design (50 blows per side of the specimen) is used to simulate medium traffic volume and compaction. In this experiment, there are three variables which are bitumen content, bones content and GGBS content. All the variables are taken in three proportions to observe the performance within the range. For bitumen, chosen proportions are 4.5%, 5%, and 5.5%. For bones and GGBS content chosen proportions are 5%, 10% and 15%. From related previous works, it is observed that expected optimum lies within the range.

In this test, at least three specimens for each combination of aggregates and mixing bitumen content were prepared. The bitumen was of penetration grade 70. All the aggregates used were oven-dried. Around 64% of coarse aggregate, 31% of fine aggregate and 5% of mineral filler stone dust in proportion chosen for the mix design. Bones and GGBS of design proportion and bitumen content chosen for the sample preparation of design mass, of around 1216g (for 5% bitumen) to ensure a theoretical density of 2.4-2.5 g/cc for the cylindrical samples. The aggregate of design quantity in correct proportion was mixed with design bones and GGBS in a hot pan which was stirred uniformly to give a homogeneous mix at a temperature of 105-110oC. The weighed bitumen for a sample was added to the heated aggregated mix. The bitumen was heated to a liquid state and mixed well with the aggregate to get a homogeneous state mixture at 105-110o C. The specimen was compacted with 50 blows to each side of the cylindrical sample mounted on a standard mold assembly with a standard Marshall hammer that has a circular tamping face 98.4 mm (3.88 in.) in diameter and a weight of 4.5 kg (10 lb.) with a free fall of 457mm (18 in.) to get the Marshall compaction specimen. The compacted specimen was allowed to cool down to room temperature before the extraction of the sample. Then it was placed on a smooth level surface until ready for testing. Normally specimens are allowed to cool overnight.

The stability of materials for the design of Marshall bitumen requires that a number of tests are performed on the materials. The stability-flow test measures the maximum load resistance and corresponding deformation (or flow) of a standard test specimen when subjected to a load by a standardized test procedure. Marshall method of analysis is undertaken to record the stability, flow, and others the volumetric performance of all the samples. Stability and flow values are directly accessible from the gauge reading of the Marshall apparatus. Formulas based on materials properties are used to record the volumetric properties of samples like air voids (V_a), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), effective asphalt content (P_{be}), Bulk Specific Gravity (G_{sb}), Effective Specific Gravity (G_{se}), Aggregate content(P_s), Asphalt content(P_b) etc.

The formula used in this experiment for bitumen properties are given below:

$$G_{mb} = \frac{W_a}{W_s - W_w} \quad (1)$$

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}} \quad (2)$$

$$P_s = 100 - P_b \quad (3)$$

$$P_{mm} = 100 \quad (4)$$

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}} \quad (5)$$

$$G_{sb} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}} \quad (6)$$

$$\%V_a = 100\frac{G_{mm} - G_{mb}}{G_{mm}} \quad (7)$$

$$\%VMA = 100 - \frac{G_{mb}P_s}{G_{sb}} \quad (8)$$

$$\%VFA = \frac{\%VMA - \%V_a}{\%VMA}100 \qquad (9)$$

The limits of the Marshall parameters namely stability, flow, air voids, VFA, VMA are as follows: -

Table 1: Limiting values of Marshall Parameters: (For medium traffic)

Marshall parameters	**Limiting values**
Stability, N (lb.)	5338 (1200)
Flow, 0.25mm (0.01 in.)	2 to 4
Percent air voids	3 to 5
Percent voids filled with asphalt(VFA)	65 to 78

Source: (Paul H.W and K. Dixon, 2004)

For the analysis of the samples, six graphs are prepared namely:

(1) Unit weight vs. Percent AC by wt. of mix (where AC indicates Asphalt Content equivalent to bitumen content),
(2) Percent air voids vs. Percent AC by wt. of mix,
(3) Marshall stability vs. Percent AC by wt. of mix,
(4) Percent VMA vs. Percent AC by wt. of mix,
(5) Flow (1/100) in. vs. Percent AC by wt. of mix,
(6) Percent VFA vs. Percent AC by wt. of mix.

The shape of the curves help to determine whether the samples are giving results within acceptable range. The standard shape of the specified six graphs look like this:

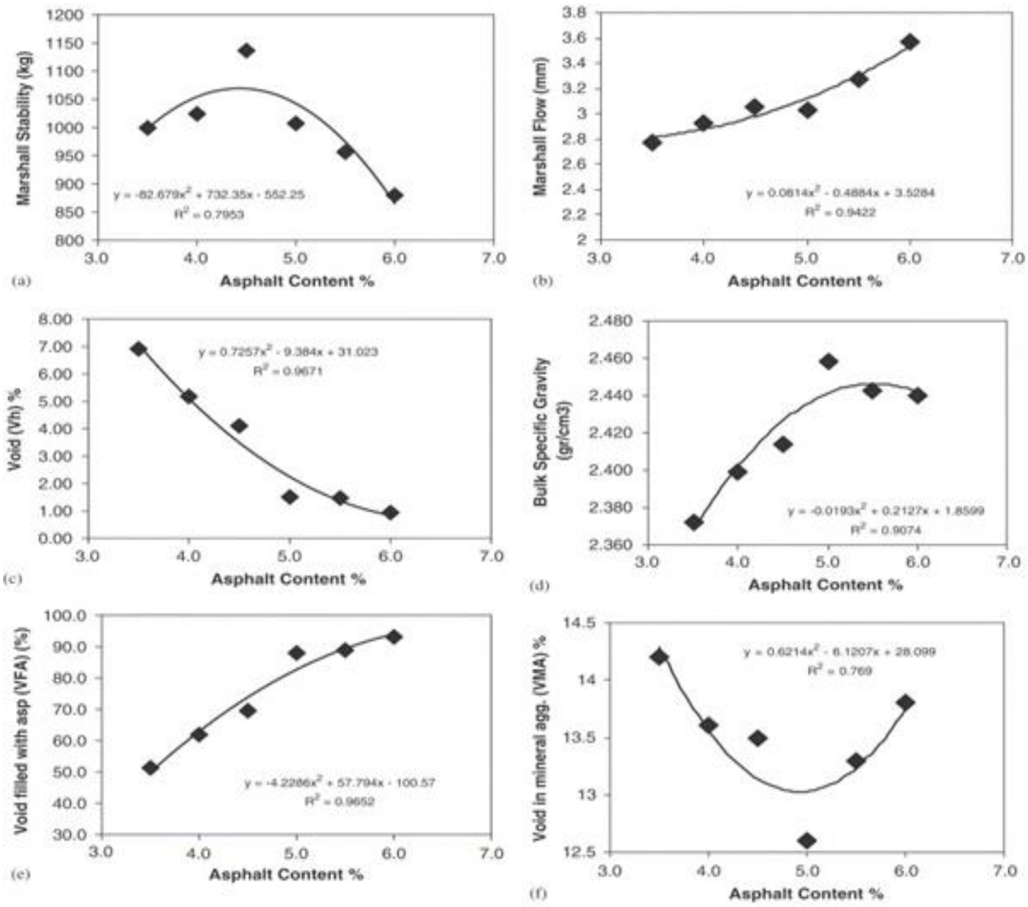


Figure 1: Test property curves for hot-mix design data by Marshall Method
Source: (Paul H.W and K. Dixon, 2004)

To analyze the performance of bones and the GGBS mix, the Marshall method is applied extensively. Among the three variables namely bitumen content, bones content and GGBS content, two variables are kept constant at a time and the other is changed and the sample is analyzed by the Marshall method of analysis. Here the analysis of optimum binder content for each mix (of bones and GGBS) is derived and corresponding values of stability, flow, air voids, VMA, unit weight, and VFA are recorded.
The samples were prepared according to this experimental design:

Table 2: The bones and GGBS combination of three design proportions with three proportions of bitumen content (70 penetration grade) give 18 sample for this experiment

Bitumen Content	Bones	GGBS
4.5%	5%	10%
	10%	
	15%	
	10%	5%
		10%
		15%
5%	5%	10%
	10%	
	15%	
	10%	5%
		10%
		15%
5.5%	5%	10%
	10%	
	15%	
	10%	5%
		10%
		15%

Here, % of Bitumen (of Total Mix), P_b for different percentage is 4.5% = 54.42 gm, 5.0% = 60.79 gm, 5.5% = 67.22 gm.

Specific Gravity

C.A. (1 inch - #8) (G_1): 2.68 (ASTM C-127)
F.A. (#8 - #200) (G_2): 2.68 (ASTM C-128)
M.F. (Passing #200) (G_3): 2.77 (ASTM D-854)
Bitumen (G_b): 1.02 (ASTM D-5)

3. RESULTS AND DISCUSSION

At first the penetration test was done to see the changes in bitumen.

Table 3: Penetration test result:

	(%)	Penetration Result
Bones (%)	5	67.33
	10	63.68
	15	63
GGBS (%)	5	65
	10	64.33
	15	65.68

From Table 3, it is clear that the additives were able to decrease the penetration which also means the consistency of bitumen somewhat decreased. The lower the consistency, it becomes more suitable for warmer countries because it gives less scope of deformation or rutting. In hotter areas, lower penetration grades area unit most well-liked to avoid softening whereas higher penetration grades like 180/200 area unit utilized in colder areas to forestall the prevalence of excessive brittleness.

All the test sample were made for medium traffic (for sample compaction, 50 blows per face) specification for Marshall Test and will be analysed for medium traffic also. After acquiring all the data from the test and the value of air void, VMA, VFB, by the equations 7, 8, 9 respectively.
The Marshall parameters of the tested specimen are given below:

Table 4: Marshall Analysis data obtained from samples:

Specimen No,	Bitumen Content (%)	Bones (%)	GGBS (%)	Air Void (%)	Unit Weight (pcf)	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
1	4.5	5	10	3.93	155.613	11.267	65.157	6.727	3.23
2		10		4.398	154.849	11.703	62.424	6.837	3.21
3		15		4.788	154.2171	12.063	60.312	6.447	3.34
4		10	5	4.950	153.954	12.213	59.469	6.658	3.28
5			10	4.829	154.149	12.102	60.094	6.932	3.17
6			15	4.792	154.209	12.067	60.288	6.898	3.22
7	5	5	10	3.892	156.450	11.257	65.427	6.933	3.18
8		10		4.011	156.257	11.367	64.715	7.362	2.87
9		15		4.168	156	11.512	63.792	7.382	2.88
10		10	5	4.207	155.936	11.549	63.565	7.835	3.2
11			10	4.050	156.192	11.403	64.481	7.007	3.1
12			15	4.089	156.128	11.439	64.251	7.146	2.98
13	5.5	5	10	4.058	156.965	11.433	64.504	7.785	2.95
14		10		4.099	156.898	11.471	64.267	8.243	2.89
15		15		3.860	157.289	11.250	65.689	8.367	2.87
16		10	5	4.531	156.192	11.869	61.829	7.877	2.95
17			10	4.452	156.320	11.797	62.259	8.011	2.9
18			15	4.413	156.385	11.761	62.479	7.967	2.92

After these data were obtained, total 36 graphs were plotted for individual sample using the data from Table 4. Also 12 graphs were plotted which included the individual parameters against the various percentage of bitumen content and the individual performance of waste bones and GGBS. This was done to obtain optimum bitumen content for various parameters, and average optimum bone and GGBS content for best possible results. This whole extensive analysis result can be summarized as below:

Table 5: Summary of Parameter Analysis:

	Minimum	**Maximum**
Flow Value	2.87 mm for both 5% bitumen, 10% GGBS and 10% bones and 5.5% bitumen, 10% GGBS and 15% bones.	3.34 mm for 4.5% bitumen with 10% GGBS and 15% bones
Comments on Flow Value	• Optimum bitumen content based on flow analysis is 5.5%. • Average optimum bone content is 12.5% • Average optimum GGBS content is 10%	
Stability Value	6.447 kN for 4.5% bitumen, 10% GGBS and 15% bones	8.367 kN for 5.5% bitumen with 10% GGBS and 15% bones
Comments on Stability Value	• Optimum bitumen content based on stability analysis is 5.5% • Average optimum bone content is 15% • Average optimum GGBS content is 10%	

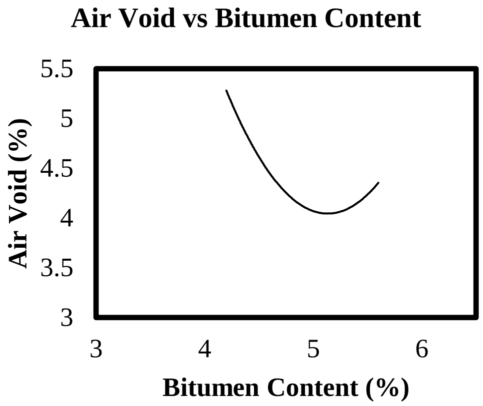
Air Void Value	3.86% for 5.5% bitumen, 10% GGBS and 15% bones	4.95% for 5.5% bitumen with 5% GGBS and 10% bones
Comments on Air Void Value	• Optimum bitumen content based on air void analysis is 5.5% • Average optimum bone content is 15% • Average optimum GGBS content is 10%	
VMA Value	11.25% for 5.5% bitumen, 10% GGBS and 15% bones	12.213% for 4.5% bitumen with 5% GGBS and 10% bones
Comments on VMA Value	• Optimum bitumen content based on air void analysis is 4.5% • Average optimum bone content is 10% • Average optimum GGBS content is 5%	
VFB Value	59.47% for 4.5% bitumen, 5% GGBS and 10% bones	65.43% for 5% bitumen with 10% GGBS and 5% bones
Comments on VFB Value	• Optimum bitumen content based on air void analysis is 5% • Average optimum bone content is 5% • Average optimum GGBS content is 10%	
Unit Weight Value	153.95 pcf for 4.5% bitumen, 5% GGBS and 10% bones	157.3 pcf for 5.5% bitumen with 10% GGBS and 15% bones
Comments on Unit Weight Value	• Optimum bitumen content based on air void analysis is 5.5% • Average optimum bone content is 15% • Average optimum GGBS content is 10%	

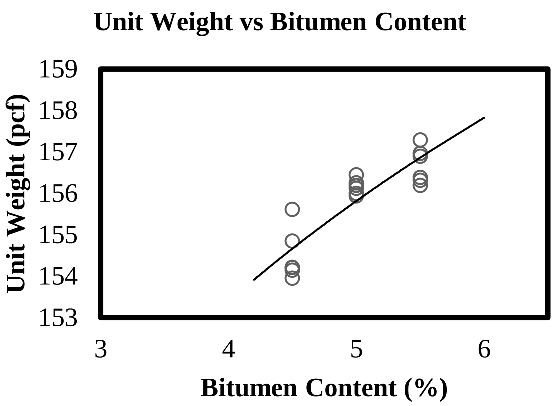
Table 6: Comparison of best possible experimental value with Table 1 for medium traffic:

Parameters	Standard Values	Experimental Values	% Decrease/Increase
Stability (kN)	Minimum 5.3 kN	Max. 8.367 kN	57.86% Increase
		Min. 6.45 kN	21.7% Increase
Flow (mm)	Maximum 4 mm	Min. 2.87 mm	28.25% Decrease
		Max. 3.34 mm	16% Decrease
Percent Air Void (%)	Maximum 5%	Min. 3.86%	22.8% Decrease
		Max. 4.95%	1% Decrease
VFB (%)	Minimum 65%	Max. 65.7%	1.1% Increase
		Min. 59.47%	8% Decrease
VMA (%)	Minimum 17%	Max. 12.2%	28.23% Decrease
		Min. 11.25%	34% Decrease

The Marshall parameters were individually analysed. From Table 6 it was observed that the flow decreased to 28.25%. This means that the experiment was able to successfully decrease the flow to a considerable amount. Flow gives a general idea about the deformation corresponding to the load-carrying capacity of the design mix meaning it is such a point where the load begins to decrease. For a considerable good design, always a lower value of flow is expected, as the higher value indicates too much deformation under specific load and weather conditions. In this experiment, the optimum bitumen content based on flow was 5.5% as the flow decrease rate is higher. From Figure 2 it seems that GGBS gives better results at 4.5% bitumen content while bones give better results at 5% and 5.5% bitumen content. Stability measures the maximum load resistance of bitumen mix design. A higher value suggests that the mix design has a higher load capacity. Observing Table 4, it is seen that stability increases in most cases. Especially, for 5.5% bitumen and 10% GGBS with corresponding bones variable gives a good result. Considering the minimum and maximum values from Table 6, the value has increased by 57.86% of the standard value. Though the test was carried out for medium traffic, some of the values reached the minimum stability requirement for heavy traffic. The optimum bitumen content based on stability analysis was 5.5%, and average bones and GGBS optimum content was 15%

and 10% respectively (Table 5). Also (Figure 2) it seems that GGBS gives better result at 4.5% bitumen content while bones gives better results at 5% and 5.5% bitumen content which is similar to flow results and it gives the most obvious indication that with increasing stability the flow decreases as the relationship between stability and flow is reversely proportional. This was attributed to the specific gravity of additive which is less than that of bitumen. This serves to penetrate between particles and enhanced the interlock of aggregates, which increases the stability and decreases the flow value. It should be emphasized that the design range of air voids (3 to 5 percent) is the level desired after several years of traffic. This is a very important parameter regarding the design as more air voids indicates higher permeability to water and air which causes heavy damage to waterproof and the consequence of this situation is a mix that hardens prematurely, becomes brittle and cracks at an early age or the aggregate ravels out of the mix because of the loss of asphalt adhesion. Again if the air void is less than minimum prescribed value than there is no space for future compaction leading to rutting. Still from Table 6, it is notable that the air void did not surpass or fall behind the prescribed limits. Moreover, the experiment was able to decrease the air void up to 23%, though some of the results show values reaching almost 5% air voids. The optimum bitumen content based on air void was 5.5% which means in this bitumen content the specimen had fewer air voids but not less than the minimum specified value. VMA is a representation of the voids in the mineral aggregate which also includes air voids and the effective bitumen content. For the different percentages of variables, it gives different results. Especially from observing Table 6 the VMA value decreases from the minimum standard value considerably up to 34% which is not desired. So this parameter should be thoroughly investigated further. VFB represents the voids filled with bitumen. In this experiment, the VFB results were slightly unsatisfactory. Maximum values are below the minimum specific requirement and some value was just at the threshold of the minimum requirement (at least 8% decrease from Table 6). This indicates that most of the voids were not filled properly. This may happen due to the variety of mixture and compaction throughout the experiment. Though unit weight does not have any specific limit for this test, it gives an idea about the relationship between the specific gravity of aggregates and voids. Good compaction gives maximum unit weight with fewer voids. In this experiment, from Table 5, 5.5% bitumen content showed maximum unit weight.





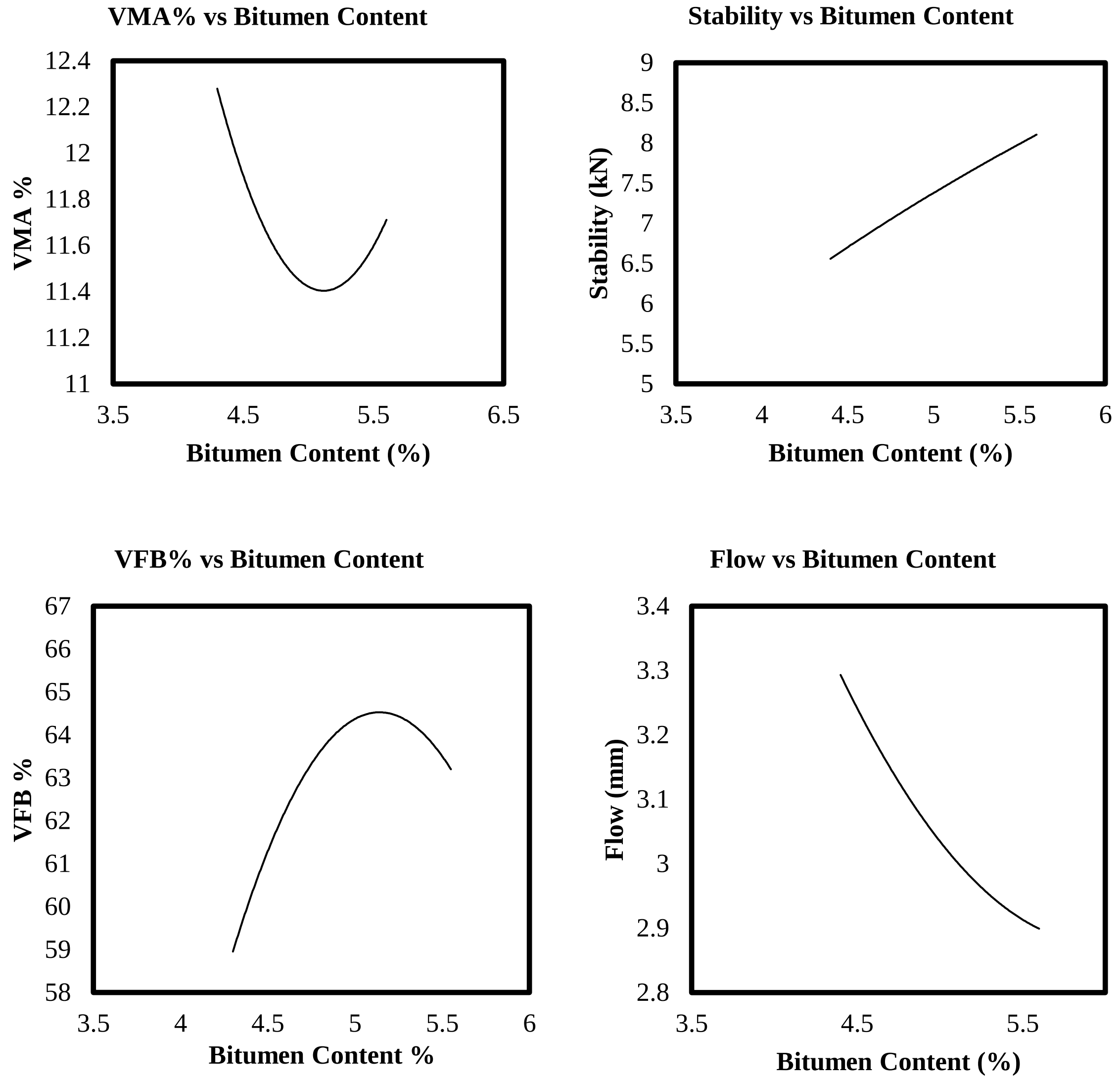


Figure 2: Marshall Method curves obtained from using data from Table 4.

If we compare Figure 1 and Figure 2, the obtained Marshall Test property curves followed the general behavior pattern quite similar to the standards except for the stability and flow curve. Generally, the stability and flow decreases and increases respectively with increasing bitumen content. But in the obtained result stability kept increasing and the corresponding flow kept decreasing. This phenomenon only indicates that the optimum bitumen content may be higher in modified bitumen content than generally used. Mix design is a compromise of many factors. The bitumen content that provides the best overall performance in addition to passing the previously discussed conventional criteria would be considered the design value. In this experiment, VFB and VMA criteria were slightly fluctuating, but other parameter results were very satisfactory, especially flow and stability of the samples.

4. CONCLUSIONS

The overall summary of the experiment is:

- The addition of the additives successfully increased the stability and the best result include 57.86% increase and decreased the flow rate up to 28.25% which is highly desired for a sustainable and long-lasting pavement surface. This result was expected for high volume traffic but was achieved only using medium volume traffic specification which indicates that more amazing results can be obtained with these additives using high traffic volume specification.

- Most of the good results for different parameters were obtained for 5.5% bitumen content and so it is the optimum value for this design.
- The air void was within the standard limit which is also desired for long-lasting pavement design. Except for VMA and VFB, all other parameters gave desired results with the addition of GGBS and waste bones.
- Some slight adjustments in the mix design involving the aggregate size is required to obtain desired VMA and VFB as the value was slightly fluctuating.

This experiment was an initial step to see the effects of the two additives over bitumen and the result show that these additives have positive effect over mix design.

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