The International Journal of Engineering and Science (IJES)
|| Volume || 7 || Issue || 3 Ver. II || Pages || PP 64-72 || 2018 ||
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805

Evaluation of the Performance of Brick Dust as a Filler Material for Hot Asphalt Mix Design: A Case Study in Jimma Zone

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ABSTRACT

A bituminous paving mixture is a mixture of coarse aggregate, fine aggregate, and bitumen mixed in suitable proportion to result in the strong and durable mix in order to withstand traffic load. In this paving mix, ordinary stone dust, and cement used as filler material. One of the main problems in the construction of bituminous paving mixture is the insufficient amount of filler from crushing stone aggregate, and cement supply is low. A study has been carried out in this research to explore the use of Brick dust as filler material for the bituminous mixture. The objective is intended to evaluate the performance of brick dust as fillers in Hot Asphalt Mix design, according to the test procedure specified by ASTM. Several specimens of hot asphalt mixture were prepared according to ASTM D 1559 using an aggregate blend with brick filler and aggregate blend without brick filler. The aggregate blending made by using Job mix formula to obtain the percentage of mixed material. For aggregate blended without brick G-1 32%, G-2 23%, and G-3 45% for Aggregate blended with brick filler G-1 30%, G-2 18%, G-3 45% and G-4 7%; where G-1 Coarse Aggregate 3/4, G-2 Coarse Aggregate 3/8, G-3 Fine Aggregate, and G-4 brick filler. It concluded that the results of the Marshall test of mix design showed satisfactory when hot asphalt mixed with these brick fillers. The Specimens blended with brick filler lead in produce asphalt mixture with higher Marshall stability, lower flow, a less void filled with asphalt. Hence, brick dust can replace stone dust and cement filler in the bituminous paving mix. It is recommended to use brick dust as filler material in a bituminous paving mix may save considerable investment; as well as reliable performance of the in-service highway can be achieved.

Keywords: *Aggregates, Brick Filler, Bituminous paving mix, Hot Mix Asphalt, Marshall Mix Design, Optimum Asphalt Content.*

Date of Submission: 12-03-2018 Date of acceptance: 27-03-2018

I. INTRODUCTION

Construction of highway involves a huge outlay of investment. A precise engineering design may save considerable investment as well a reliable performance of the in-service highway can be achieved. Two things are of major considerations in flexible pavement engineering; pavement design and the mix design. The present study is related to the mix design considerations. A mix designer tries to achieve these requirements through some tests on the mix with different proportions and finalizes with the best one [1]. The road usually shows excessive failures at an early stage of the pavement life. A primary procedure in the improvement of the existing performance of roads starts with modification of mix design. The strength, cost, and stability of asphalt mixtures are influenced by several features together with a gradation of aggregated and types and amount of filler materials. The filler plays a major role in the properties and behavior of bituminous paving mixtures [2]. The mechanical properties of bituminous road pavement depend decisively upon the properties of its filler-bitumen [3]. For modification of asphalt paving materials, the high-quality additives are quite expensive for the mass production of bituminous mixtures, a solution to this problem can be obtained by considering the influence of natural mixture ingredients, such as filler [2]. Mineral fillers were originally added to the dense-graded HMA paving mixtures to fill the voids in the aggregate skeleton and to reduce the voids in the mixture [4]. The filler used in the asphalt mixture is known to affect the mix design, especially the optimum asphalt content. Fillers not only fill voids in the coarse and fine aggregates but also affect the aging characteristics of the mix. The aggregate materials those are finer than 75μm in size is referred to as filler. The use and the application of mineral filler in asphalt mixtures are intended to improve the properties of the binder by reducing the binder's inherent temperature susceptibility [2]. The filler theory assumes that "the filler serves to fill voids in the mineral aggregate and thereby create the dense mix," [5]. Filler particle is beneficial because of increased resistance to displacement resulting from the large area of contact between particles. It found out that fillers increase compaction effort required to compress specimens to the same volume or air void content. The function of mineral filler is essential to stiffen the binder. According to various studies, the properties of mineral fillers, especially the material passing 0.075 mm (No. 200) sieve, have an essential effect on the performance of asphalt paving mixture regarding deformation, Fatigue cracking, and moisture susceptibility [6]. Some conventional construction materials like lime, cement, granite powder are commonly used as filler in asphalt concrete mixture worldwide. Cement, lime and granite powder are expensive and are used for other purposes more effectively. With the economic point of view, my present investigation has been taken to study the performance of asphalt concrete mixed with Brick-dust in the hot asphalt mix.

II. MATERIALS AND RESEARCH METHODOLOGY

2.1 Materials

Several materials were required for producing asphalt specimens. Since the main objective of the study was to investigate the performance of Brick as the filler concerning overall parameters asphalt pavement mix, it was important to evaluate not only Brick but also various aggregate and binder sources.

2.1.1. Mineral Aggregate

2.1.1.1 Coarse Aggregate

Coarse Aggregate Should produces by crushing sound, un-weathered rock or natural gravel. The specifications for the aggregates are similar to those for a granular base course. The aggregates should be clean and free of clay and organic material; the particles should be angular and not flaky. Gravel should be crushed to produce at least two fractured faces on each particle. Aggregates for wearing course must also be resistant to abrasion and polishing. Highly absorption of bitumen must be taken into account in the mix design procedure.

2.1.1.2. Fine Aggregate

Can be crushed rock or natural sand and should be clean and free from organic impurities. It shall be fraction passing 600 microns and retained on 75micron sieve, and its function is to fill up the voids of the coarse aggregate.

2.1.2. Fillers

Mineral fillers can be crushed rock fines, Portland cement or hydrated lime to assist the adhesion of the bitumen to aggregate and fill up the void. It should be the inert material which passes 75-micron sieve. However, an addition of mineral fillers has the dual purpose when added to asphalt mixtures. Different types of mineral fillers are used in the SMA mixes such as stone dust, ordinary Portland cement (OPC), slag cement, fly ash, hydrated lime etc. [7] Used waste marble dust obtained from shaping process of marble blocks and limestone as filler and optimum binder content was determined by Marshall Test and showed good result. [8] Utilized municipal solid waste incinerator (MSWI) fly ash as a partial replacement of fine aggregate or mineral filler in stone matrix asphalt mixtures. They made a comparative study of the performance of the design mixes using Super pave and Marshall Mix design procedures.

2.1.3. Asphalt Binder

Asphalt binder is material having a wide range of consistency from fluid to hard and brittle for flexible pavement construction. Asphalt binder is commonly characterized by their physical properties. This is because an asphalt binder's physical properties directly describe how it will perform as a constituent in Asphalt mix. Different quality tests were carried out on the asphalt cement during this study to assess its physical properties through various laboratory steps.

2.2. Methodology

To evaluate the Marshal Mix properties in the laboratory using Brick as main Filler mineral and to compare with traditional fillers namely crushed stone is the focused on the research. This study starts with preparation and investigation the properties of the raw material for the marshal mix. The material used for the mixture includes coarse aggregate, Fine aggregate, Mineral filler (Brick) and asphalt binder.

The materials as mentioned earlier were subjected to various laboratory test to determine their physical properties, whether they can meet standard specification and to assure the quality assurance. The quality assurance test conduct on the aggregate is the determination of the aggregate material properties Toughness, Gradation, Abrasion, Durability, Soundness, Specific gravity and water absorption. For the asphalt binder penetration test, ductility, durability, purity and specific gravity and for the filler material the study investigates the specific gravity and the PI. All analysis of aggregate; asphalt binder, brick filler, and compacted specimens were conducted according to respective ERA, AASHTO, ASTM, and BS testing standards.

III. RESULTS AND DISCUSSION

3.1. Aggregate Gradation of Mix Design

HMA is graded by percentage of different-size aggregate particles it contains. Figure 3.1 illustrates HMA gradations without blending with brick dust filler which is the standard gradation used as a control for the study. Specific terms are used in referring to aggregate fractions: Course aggregate -G-1 ¾ inch, Coarse Aggregate -G-2, 3/8 inch, Fine Aggregate - G-3, Brick Mineral Filler & dust– G-4

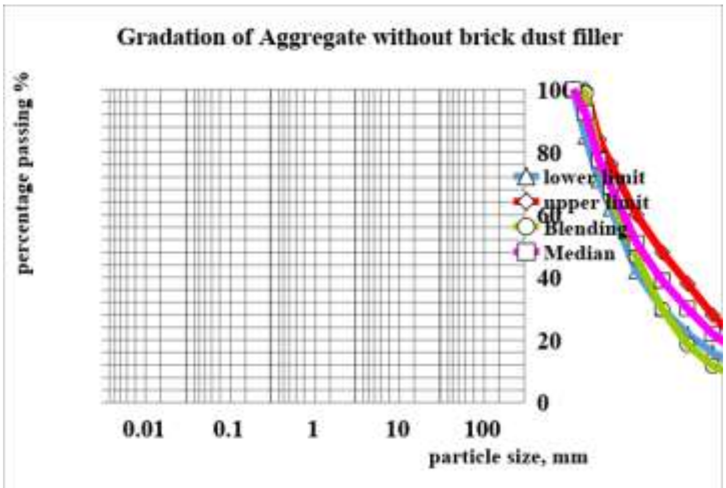


Figure 3.1: Gradation of aggregate combination before mixing with Brick material

The above figure shows that the aggregate blend without brick dust filler for the Marshall Mixture preparation, which shows the blend G-1, 32%, G-2, 23%, and G-3, 45%.

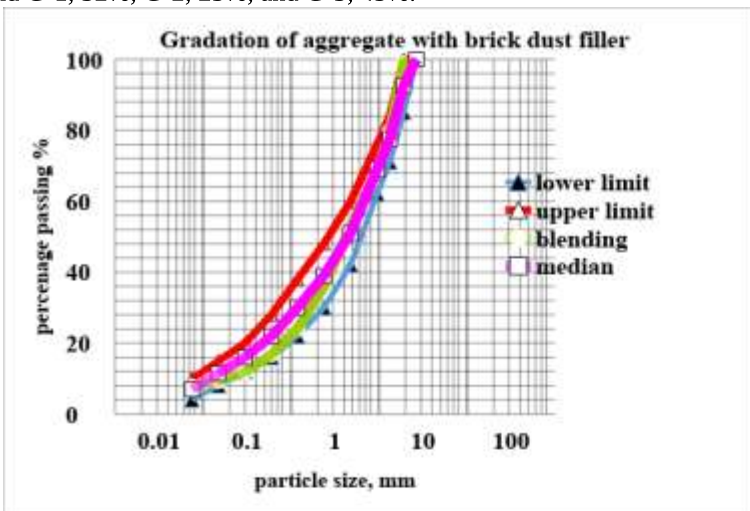


Figure 3.2: Gradation of aggregate blend after mixing with Brick material

From figure 3.1, the blended needs somehow filler material to be in the specification lower and upper limit. To satisfy the specification the upper and lower limit was used a job mix G-4. Seven percent (7%) blended with the aggregate of G-1, 30%, G-2 18%, G-3 45% provided a correct aggregate blend for the Marshall Mix design, as seen from figure 3.2 above.

3.1. Aggregate Physical Properties

To investigate the physical properties of the aggregates and their suitability in road construction, various tests were conducted, and the results are indicated in Table 3.1. The specific surface area was determined, for each of the aggregate size distribution; by multiplying surface area factors by the percentage passing the various sieve sizes and adding together. As can be seen from the results, the filler content increases in the aggregate proportion, the specific surface area will also increase.

		Test Method	Result	Specification

No	Test Description					requirements (ERA Manual 2002)
		ASTM	AASHTO	BS		
1	Los Angeles Abrasion, %	AASHTO T 96			18.8	< 30
2	Aggregate Crushing Value, ACV, %	BS 812 part 104			17.91	<25
3	Durability and Soundness, %	ASTM C 128			5.3	<12
4	Coarse Aggregate Specific Gravity (Bulk) (kg/m^3)	AASHTO T 85			2.72	N/A
5	Fine Aggregate Specific Gravity (Bulk) (kg/m^3)	AASHTO T 84			2.59	N/A
6	Coarse Aggregate Specific Gravity (Apparent) (kg/m^3)	AASHTO T 85			2.86	N/A
7	Fine Aggregate Specific Gravity (Apparent) (kg/m^3)	AASHTO T 84			2.87	N/A
8	Water Absorption, %	ASTM C 127			1.71	<2
9	Particle shape, Flakiness, %	BS 812, Part 110			20.1	<45

Table 3.1: Aggregate Physical properties

3.2. Asphalt Binder Properties

A series of tests, including penetration, specific gravity, softening point, flash point, ductility, and soluble in carbon tetrachloride conducted for the fundamental characteristic properties of penetration grade asphalt. The test results are shown in Table 3.2, which complies with the requirement of ERA specifications.

No	Test Description	Test Method		Result	Recommended Specification ERA for 85/100
		ASTM	AASHTO		
1	Penetration 25 ^{o}c	D 5	T 49	90	85 – 100
2	Specific gravity (kg/m^3)	D 70	T 228	1023	1020±
3	Ductility, 25 ^{o}c (cm)	D 113	T 51	100+	100+
4	Solubility, %	D 2042	T 44	99.6	Min 99
5	Softening Point, ^{o}C	D 36	T 53	46	42 – 51
6	Loss on heating, %		T 47	23	Max 100
7	Flash Point, ^{o}C	D 92	T 48	562	Min 232

Table 3.2: Asphalt properties

3.3. Brick Dust Filler

The fillers used the current study, namely crushed stone and crushed brick. Their physical properties, which are believed to be major suspects of affecting the bituminous mixture property such as gradation parameters and plasticity index, were determined as shown in Table 3.3.

Table 3.3: Laboratory test result for Brick Dust

No	Test Description	Test Method		Result	Specification requirements (ERA Manual 2002)
		ASTM	AASHTO		
1	Specific gravity (kg/m^3)	D 854 or C 88	T 100 or 104	**2.472**	N/A
2	PI, (Plastic Index)	D 423 or 424	T 89 or T 90	**NPI**	≤ 4

3.4. Analysis of physical properties of compacted HMA

The application of brick filler on aggregate had a noticeable effect on the essential physical properties of HMA. The following section analyzed and discussed the result collected within the laboratory under control condition. Marshall Test results of compacted mix types containing fine filler sand with stone dust and brick dust are tabulated in table 3.4.

Table 3.4: Marshal Test result

Asphalt Content %	Unit Weight, Mg/m3		Air Void, %		VMA, %		VFB,%		Stability, KN		Flow, mm	
	A	B	A	B	A	B	A	B	A	B	A	B
4	2.32	2.558	8	6	13.40	10.85	65.4	44.1	12.89	16.58	3.02	3.33
4.5	2.383	2.587	6.2	5.1	13.25	10.31	68.1	43.5	12.1	15.93	3.12	3.28
5	2.386	2.595	5.2	4	13.52	10.61	73.8	60.6	11.4	14.53	3.21	3.49
5.5	2.383	2.592	5.4	4.1	13.62	11.10	84.34	76.5	10.5	11.24	3.52	3.75
6	2.368	2.572	6.1	5.1	14.81	13.20	92.45	81.8	9.5	11.10	5.1	5.57

Where **A**: - Mixture Blend without Brick Filler and **B:** - Mixture Blend with Brick filler

3.5. Stability

Stability is a measure of the mass viscosity of the aggregate-asphalt cement mixture and is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement. Anything that increases the viscosity of the asphalt cement increases the Marshall stability.

The addition of brick as a filler in the hot asphalt mix result void and asphalt content decrease. So decreasing of asphalt content due to an addition of brick filler result good or high stability by avoiding wash boarding, rutting, flushing and bleeding effects caused by an excess asphalt mix. Balancing of an excess medium size of sand in the mixture by adding brick filler to reduce tenderness during compaction, which also results from good stability of the mixture.

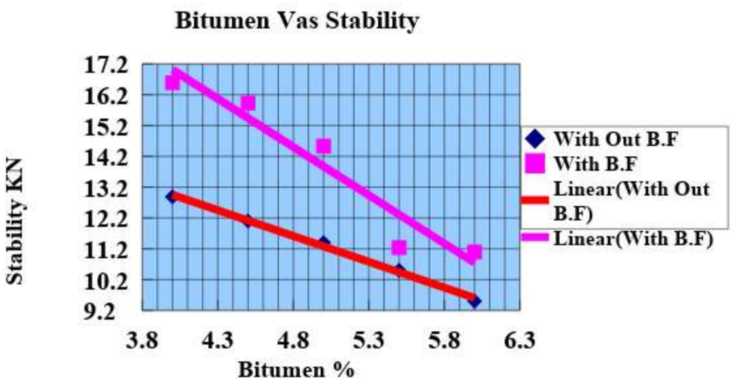


Figure 3.3: Bitumen vs. Stability

From figure 3.3, it illustrates that the addition of brick filler to the blend results, increasing of stability than of blend without brick filler. This may be due to making the brick dust filler and asphalt cement combination act as a more viscous binder thus increasing the Marshall stability. Therefore, the brick filler stiffens the asphalt film and reinforces it. That means a mixture with brick dust filler good in the resistance to deformation than that of bend without brick filler.

3.6. Unit Weight (Density)

Density parameter is essential to identify the density appropriately in the results. It will lead to excellent pavement performance. Mix properties are needed to be measured in volumetric terms as well as weight. The effect of brick filler content on the unit weight of compacted mixes is shown in Figure 3.4.

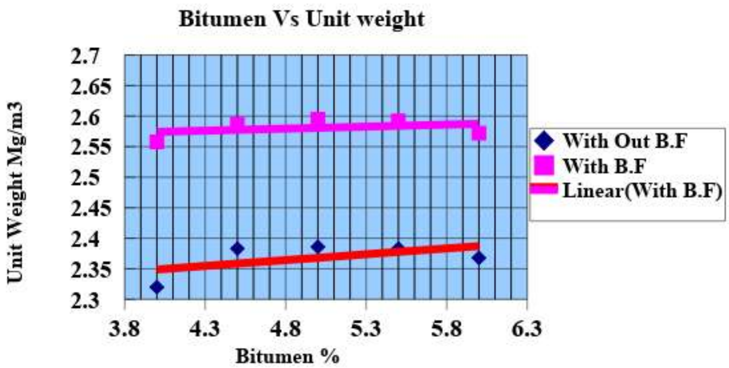


Figure 3.4: Bitumen vs. Unit weight

Mixes made with brick filler, and without brick, filler showed a trend of increase up to maximum and then decreases as the filler content increases. But the starting point of the unit weight different the mix with Brick filler start with the Unit weight of 2.558 mg/m^3 and the blend not mix with brick filler starts with the unit weight of 2.32 Mg/m^3 ending with 2.572 Mg/m^3 and 2.368 Mg/m^3, respectively. It may be due to making the brick dust filler and asphalt cement combination act as a more viscous binder thus increasing the Marshall stability. Therefore, the brick filler stiffens the asphalt film and reinforces it. It means, while the filler content rises in the mix, it fills the voids hence it increases the unit weight. However, at higher content, the combination becomes stiffer that needs greater compaction effort, which consequently lowers the dense mixture obtained.

3.7. Voids in Mineral Aggregate (VMA)

This total amount of voids significantly affects the performance of a mixture because, if the VMA is too small, the mix may suffer durability problems, and if the VMA is too large, the mix may show stability problems and be uneconomical to produce. It is a common trend that, as filler content in the mixes increase, the voids in mineral aggregate decrease up to minimum value then increases at higher content.

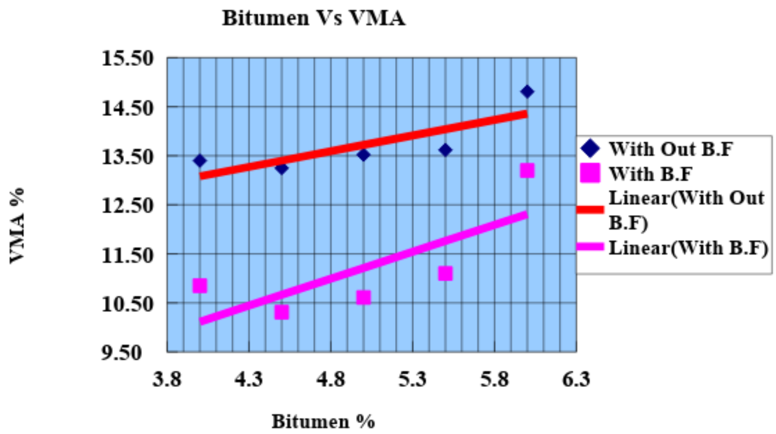


Figure 3.5: Bitumen vs. VMA

As can be seen from Figure 3.5, mixtures using both brick filler and crushed stone filler types exhibit the same behavior, but mixes made using brick filler in the mid-range of the specification, hence it is durable and economical to be used. It can be observed from Figure 4.3 that VMA decreases with the addition of brick dust filler to the bituminous mixtures. The result could be due to the decrease of bulk specific gravity as indicated by an equation for VMA. But all the results are within the specification range, which also supports the use of these brick dust as filler.

3.8. Voids Filled with Asphalt (VFA)

A void filled with asphalt (VFA) is the percentage of inter-granular void space between the aggregate particles (VMA) that contains or is filled with asphalt. Most specifications include percent VFA requirements range from 65 - 80 percent. VFA depends on both VMA and Va values from the cumulative effects of these two variables are shown in Figure 3.6. The mixed blend with brick filler is minimized the void filled with asphalt when it's compared with asphalt mix without brick filler as shown in Figure 3.6.

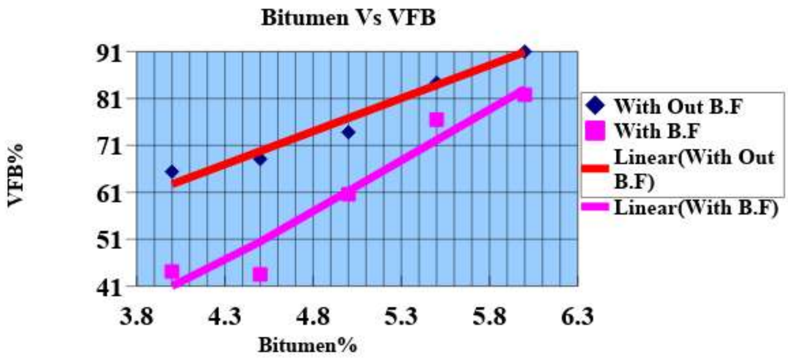


Figure 3.6: Bitumen vs. VFB

VFB of mixtures decreasing after adding brick dust as filler into the mixture, as shown in Figure 3.6, VFB which represents the volume of the effective bitumen content of the mixture is inversely related to air voids and hence as air voids decreases, the VFB increases. But from the above result, we conclude that the addition of brick dust filler to the bituminous mixture change the trend from inverse to reverse that means the addition of brick dust filler in the mixture result from the decreasing of both air void and asphalt content this is because of the brick filler fill the void that occupied by air and asphalt.

3.9. Air Voids in the Mix (Va)

Air voids may raise or lower the binder content. They may also be improved or reduced by controlling the quantity of material passing the No. 200 sieves. The finer added to the asphalt mixture, it will lower the air voids. If a plant has a baghouse dust collection system, the air voids may be controlled by the number of fines which are returned to the asphalt mixture. Finally, varying the aggregate gradation in the mix would change the air void space.

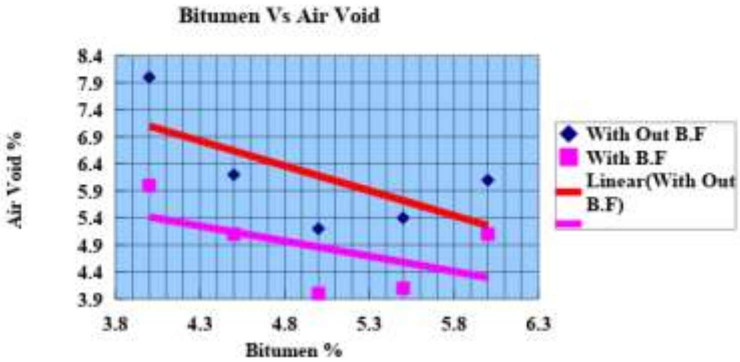


Figure 3.7: Bitumen vs. Air Void

Total void in the mix refers that the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture expressed as percent of the bulk volume of the compacted paving mixture. The asphalt mix was done by mixing the Brick filler minimize the volume of total air between the coated aggregate than that of used by stone filler self. As shown in Figure 3.7.

3.10. Flow

Flow refers that the vertical deformation of the sample (measured from the start of loading to the point at which stability begins to decrease) in 0.25 mm. High flow values indicate a plastic mix that will experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and one that may experience premature cracking due to mixture brittleness during the life of the pavement.

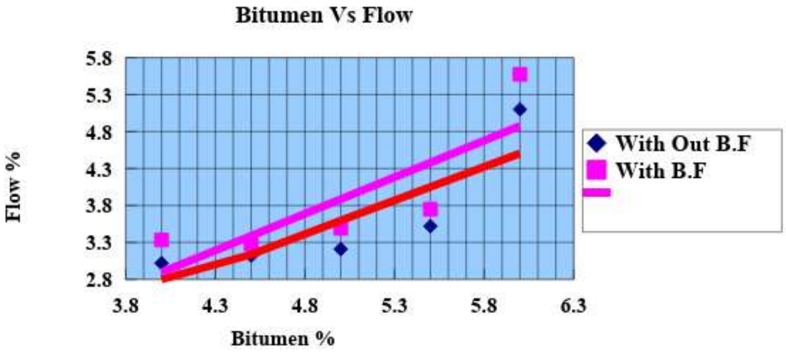


Figure 3.8: Bitumen vs. Flow

The flow value has a general trend of consistent increases with the increasing asphalt content. For 75-blow Marshall designs that are used on high volume roads, the flow value is usually specified to be in the range of 2 – 4 mm. Figure 3.8 shows that the mix of Brick filler samples increases in flow compared with the stone itself filler samples.

3.11. Optimum Asphalt Content Determination

It considered that the effective asphalt content in the mixture determines the performance of mixtures. It can be explained that it is the effective asphalt binder content that makes the asphalt film around the aggregate particles. If the asphalt film thickness around the aggregate particles is thick enough, various desirable characteristics such as better durability, more fatigue resistance, and higher resistance to moisture induced damage can be achieved from bituminous mixtures. But, there should be a maximum limit were up with the increase in temperature and loading, the asphalt content in the mix gets increased and results bleeding on the surface of a paved road.

Figure 3.9: Determination of Asphalt content with not blended with Brick Filler

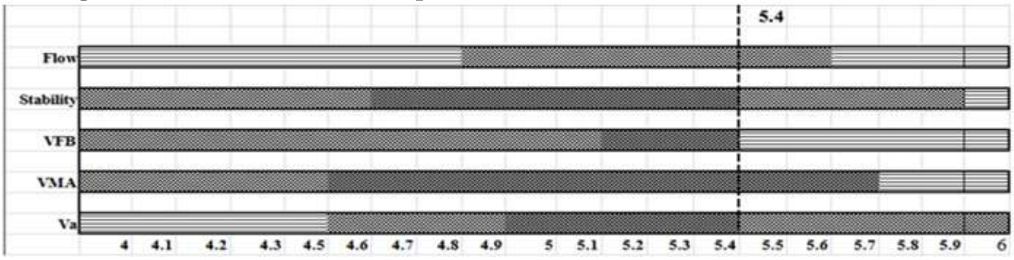
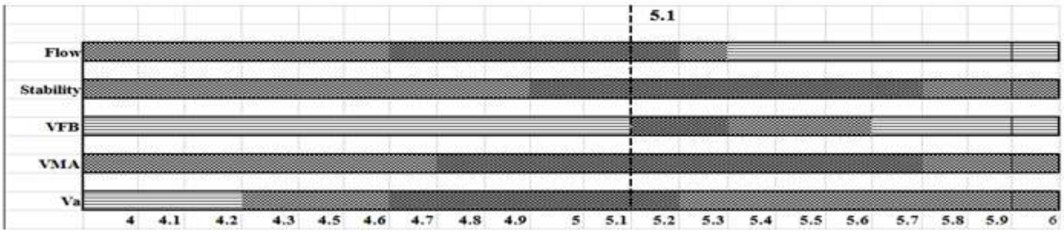


Figure 3.9 and 3.10 are plotted for the useful asphalt content that is present in mixes for the mix which not blends with brick dust filler and blend with brick dust filler. The figure shows that there exists a common trend among the filler types concerning their content in the mixture.

Figure 3.10: Determination of Asphalt content to mix with Brick Filler



That is, the effective asphalt content decreases as the filler content in the mix increases. This is probably because more voids will be filled with mineral filler as the filler content in the mix increases, which results from lower total asphalt content.

IV. CONCLUSION

- The laboratory result for brick provides specific gravity and plastic index, satisfying the specification for using filler in the hot asphalt mix so that brick can use as filler in hot asphalt mix design.
- For the mixture contain brick filler at a content of 7% gives good gradation proportion for hot mix asphalt.
- The optimum asphalt content value was required to fulfill the Marshall requirement is 5.1% for mixture contain brick filler and were the mixture which not includes brick filler require optimum asphalt content value of 5.4%. Higher bitumen content is needed to satisfy the design criteria when a mix is not blended with Brick filler. This probably because there is higher asphalt absorption to fill the void.
- Hot Asphalt Mix produced when blending with brick filler performed better under load than HAM made without combining with brick filler. Stability value of mixes, prepared with brick filler with gives 13.68 KN and mix, prepared without brick filler gives 9.65 KN with their optimum asphalt content.
- The void in mineral aggregate (VMA) values obtained relatively decreasing trend due to additional of brick in the mixture, i.e., For mixture, blend with brick filler gives 10.9% and for mixture not blend with brick filler result 13.42%.
- The void filled with asphalt (VFA) values of mixture, blend with brick filler result from 4.1% and mixture not blend with brick filler gives 5.2% were found the max value of marshal criteria this is because of the void is filled by the brick dust filler.
- The flow and Air void in the mixture value obtained indicate decreasing trend due to the addition of brick dust as filler in the mixture than mixture not blend with brick filler to obtain maximum marshal criteria values.

ACKNOWLEDGMENT

The authors wish to thank the Jimma Institute of Technology, Jimma University, and the Ethiopian Road Authority (ERA) for allowing this research project to proceed. This hard work could not be completed without the joint sponsorship program.

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Fisseha Wagaw " Evaluation of the Performance of Brick Dust as a Filler Material for Hot Asphalt Mix Design: A Case Study in Jimma Zone " The International Journal of Engineering and Science (IJES) 7.3 (2018): 64-72