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Study the Effect of Substitution Filler on performance of Asphalt Mixture

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Abstract

The major distresses in asphalt pavements are rutting, fatigue, and adhesion loss (moisture susceptibility). In this research study, two substitution fillers (Cement and Lime) were used with two different aggregate quarries (based on minerals composition) to evaluate the relatively most beneficial combination of both fillers as well as an aggregate quarry to enhance the performance life of asphalt pavements, especially in under-developed countries. Four basic tests, (Asphalt Pavement Analyzer, Four Points Bending Beam, Dynamic Modulus, and Rolling Bottle Test) that used for the most desired properties of any asphalt pavement, were utilized to access the performance properties of modified asphalt mixture. Based on all laboratory test results this research study concludes that replacement of aggregate filler with hydrated lime and cement has a beneficial effect on asphalt mix performance and to save investment by using raw material. Substitution filler improves the high-temperature rut performance and intermediate temperature fatigue performance of asphaltic concrete mixture up to 25% to that of the conventional mixture. At the same time, substitution filler has more beneficial to improve 70% adhesion properties to that of the conventional mixture.

Keywords: Substitution Filler; Rut Performance; Fatigue Performance; Adhesion Properties; Asphalt Mixture.

1. Introduction

Materials generally employed for the construction of road or airport surfaces are asphalt concrete, which is a composite form of material made from asphalt binder, aggregate, and mineral fillers. The word mineral filler is usually referred to as fine material passing sieve number 200 standard sieve sizes. This fine material contains more than 90% of the aggregate surface area and it forms most interfaces between aggregate and asphalt binder. It is also an essential material that provides better packing characteristics between the coarse and fine aggregate. To this point, researchers always try to find substitute filler for better asphalt mixture and to save investment by using the raw materials as filler. The filler is classified as fine material and used for the modification of bituminous binder and asphalt concrete mixture. So far, different types of materials such as clay particle and limestone dust are considered as filler material. Similarly, hydrated lime, fly ash, and cement are used as modified fillers. The use of ordinary Portland cement in asphalt mixture as a substitution filler can significantly increase the resistance to rutting [1]. The addition of different fillers such as hydrated lime, fly ash, silica fume, cement, and bag-house fines is known to increase the rut resistance

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of asphalt mixture [2]. Characteristics of mineral filler and their impact on characteristics of bituminous mixture varies with amount and type of filler added to the mix [3]. Cement and hydrated lime are typically used for filler modification. The modifications of filler material applying in the asphaltic concrete mixture have been studied by some researchers. Lesueur et al. (2012) [4] reported that the durability of asphalt mixture can be increased up to 10 years when 1-2% of hydrated lime is used in asphalt concrete mixture. Similarly, the addition of cement into an emulsified asphalt mixture improves the high-temperature stability of the mixes [5]. It is also observed that the utilization of cement as some part of filler in asphalt mixture can improve the adhesion properties of asphalt mixture [6, 7].

Wang et al. (2018) [8] concluded in his research that the use of cement with filler material in asphalt mixture can improve stiffness, stripping resistance, and strength of asphalt concrete mixture. Moisture susceptibility and high-temperature stability of asphalt mixture significantly improved by the addition of cement [9]. Zhou et al. (2017) [10] analyzes and compared the physical characteristics of recycled fillers with limestone filler and found a large difference between these fillers and rheological properties of asphalt mixture. Some researcher uses a wet method of mixing for modification of asphalt binder by hydrated lime. Huang et al. (2005) and Kakade et al. (2016) [11, 12] presented that moisture resistance ability of bituminous mixture found much better when hydrated lime is directly added to asphalt binder. For a thick layer of pavements, mixing of hydrated lime by a wet method of mixing give better results as compared to the dry method of mixing for fatigue life. However, for thin layers, mixing 1-2% of hydrated lime as filler material gives better results of fatigue life [13]. The addition of 1-2% of hydrated lime in un-aged asphalt mixture can be beneficial for fatigue life improvement [14]. Wang et al. (2018) [8] concluded in his research study that cement filler has a similar effect to that of mineral filler on volumetric and physical properties of asphalt mixture. Hydrated lime has been widely used for the improvement of resistance against moisture damage in asphalt binder but very limited work has been presented on the use of hydrated lime for modification of asphalt mixture [15-17]. The permanent deformation performance of asphalt mixture can be improved by adding hydrated lime as filler into asphalt mixture [18-25]. Roy et al. (2013) [26] reported that the use of limestone dust as filler is very beneficial for water sensitivity of stone mastic asphalt mixtures and Vansteenkiste et al. (2013) [27] concluded that the use of hydrated lime as the filler has a greater beneficial effect on permanent deformation. The significant factors which separate the fillers from other materials are particle size, shape, surface area, void content, mineral, physical and chemical properties [28]. For this reason, various types of fillers are introduced into asphalt mixtures for performance improvement. The complete structure of this research article presented in Figure 1.

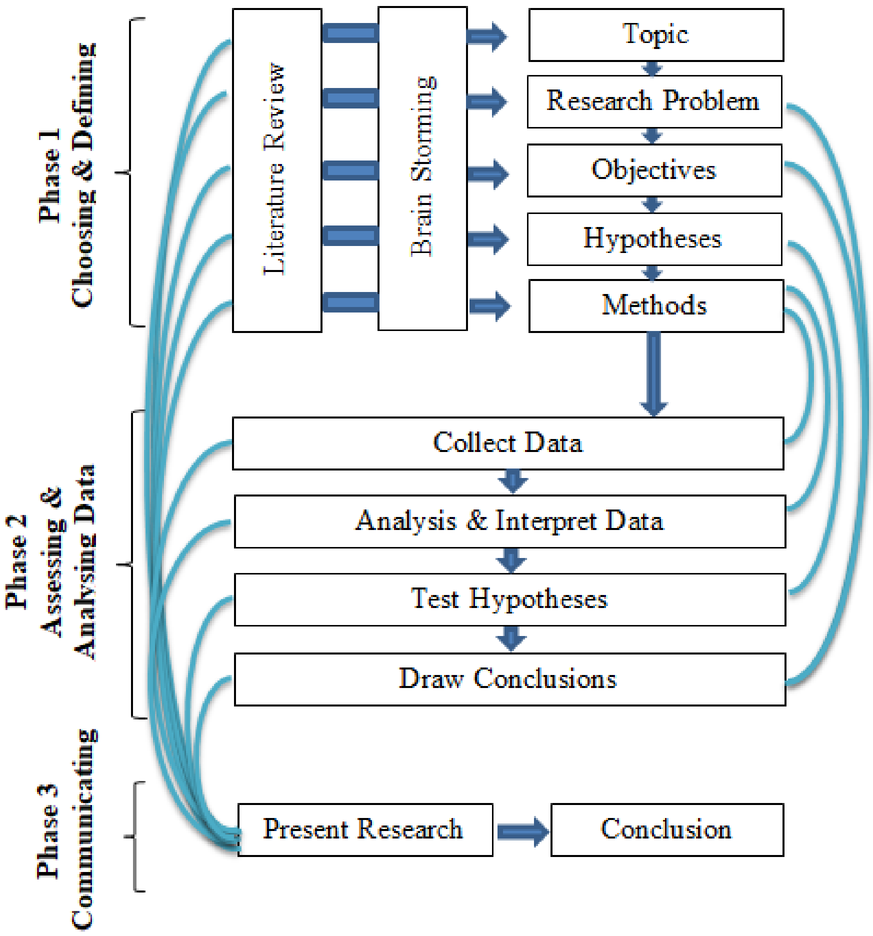


Figure 1. Schematic View of Research Article

In this research study, two substitution fillers (Cement and Lime) were used with two different aggregate quarries (based on minerals composition) to evaluate the relatively most beneficial combination of both fillers as well as an aggregate quarry to enhance the performance life of asphalt pavements, especially in under-developed countries. Moreover, lime being a raw material will not only reduce the cost but will also be eco-friendly to society. Four basic tests (Asphalt Pavement Analyzer, Four Points Bending Beam, Dynamic Modulus and, Rolling Bottle Test) that test the most desired properties of any asphalt pavement i.e. Rut resistance, Fatigue crack resistance, and moisture susceptibility were utilized to access the performance properties of modified asphalt mixture.

2. Materials and Method

The material and method which is used for the preparation of laboratory specimens and testing procedures are described in the following subsection. The summary of the research methodology has been given in Figure 2.

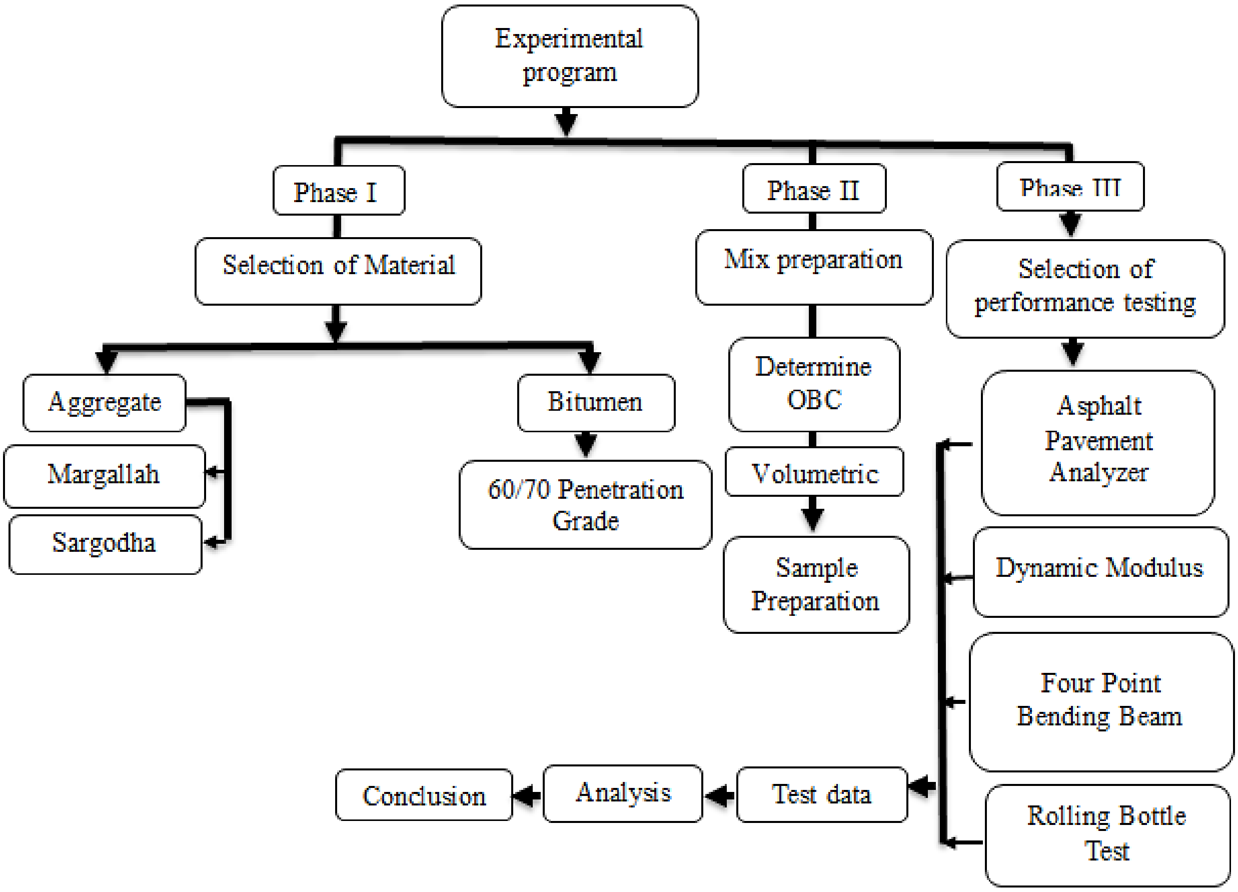


Figure 2. Research Methodology

2.1. Materials

Two types of aggregate have been selected in this study as per ASTM D3515. The aggregate has been taken from two different quarries i.e. Margallah and Sargodha. The selected aggregate has different petrography/mineralogy. Magellan aggregate has calcium carbonate minerals and Sargodha aggregate has dolerite minerals. Petrography of selected aggregate is given in Table 1.

Table 1. Petrography of aggregate

Sr. No.	Component	Formula	Calcium Carbonate	Dolerite
1	Carbonate & Calcite	$CaCO_3$ & CaO	97.2	93.4
2	Quartz	SiO_2	0.3	6.6
3	Hematite	Fe_2O_3	0.5	--
4	Clay	--	2	--

These types of aggregate have been frequently used in Pakistan for rehabilitation and new road construction projects. Mechanical and physical properties of selected aggregates were determined as per the specification of BS, ASTM, and AASHTO standards. Properties of selected aggregate are summarized in Table 2. River bed and rounded particles were not selected for this research study.

Table 2. Properties of selected aggregate

Sr. No.	Test Title	Standard	Aggregate Sources		Unit	Specification Limit
			Calcium Carbonate	Dolerite		
1	Flakiness Index	BS 812.108	5.9	8.4	%	10 (max)
2	Los Angeles abrasion Value	ASTM C 131	24	23	%	30 (max)
3	Fractured Particles (Two faces)	ASTM D 5821	100	100	%	90 (min)
4	Sand Equivalent Value	ASTM D 2419	78	75	%	50 (min)
5	Water absorption	ASTM C 127	1.01	0.97	%	2 (max)
6	Elongation Index	BS 812.109	2.2	6.4	%	10 (max)
7	Soundness (Coarse)	ASTM C 88	7.5	4.7	%	8 (max)
8	Soundness (Fine)	ASTM C 88	4.9	4.7	%	8 (max)

All the mixtures were designed with the same aggregate gradation. The graphical and tabular description of aggregate gradation is given in Figure 3 and Table 3 respectively.

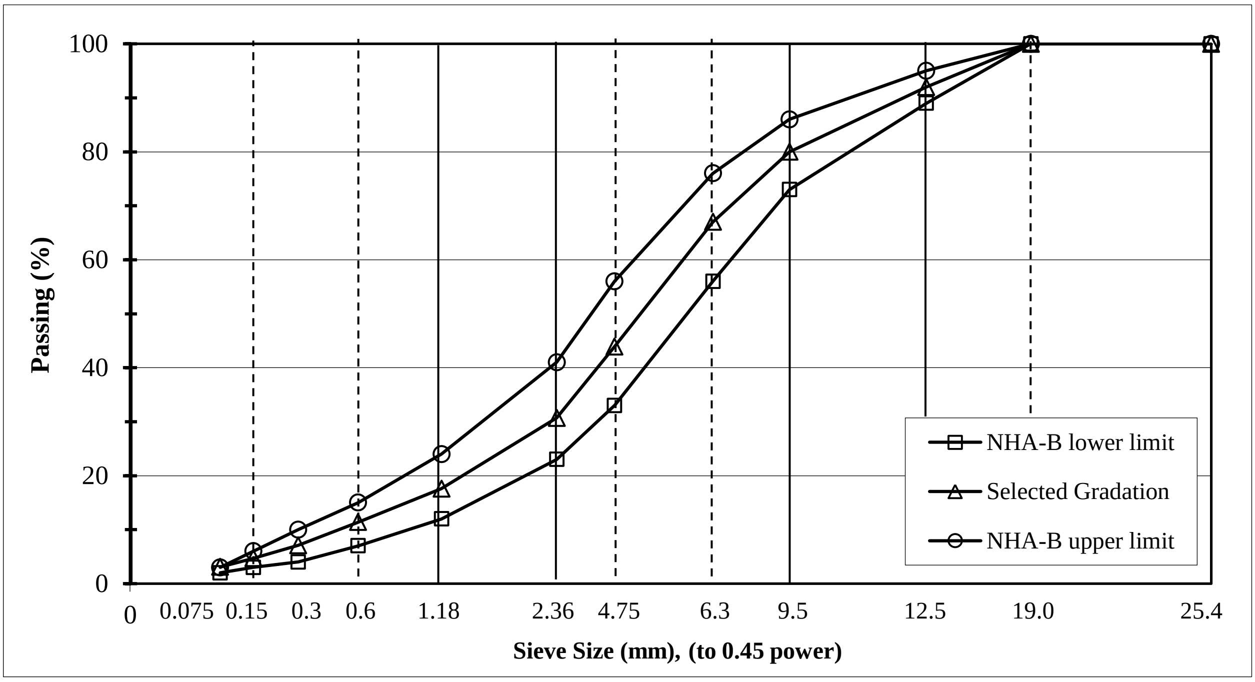


Figure 3. Selected Aggregate Gradation

Table 3. Adopted aggregate gradation

Sieve Size		Selected Gradation passing (%)	Class B Lower passing (%)	Class B Upper passing (%)
Inch	mm			
3/4	19	100	100	100
1/2	12.5	77.4	90	75
3/8	9.5	64.1	80	60
#4	4.75	39.9	60	40
#8	2.36	27.7	40	20
#16	1.18	16.6	27	12
#30	0.6	10.4	19	8
#50	0.3	8.1	15	5
#100	0.15	5.7	11	4
#200	0.075	4.1	8	3

Asphalt mixtures were designed with a 12.5mm nominal aggregate size. Six types of asphalt mixtures including three Margallah aggregate mixtures (one mixture having Margallah aggregate dust as filler, other having Portland cement as a filler and third one having hydrated lime as filler material) and three Sargodha aggregate mixtures (one mixture having Sargodha aggregate dust as filler, other having Portland cement as a filler and third one having hydrated lime as filler material) were produced. The material smaller than sieve no. 200 was replaced with the same weight of cement and hydrated lime in mixtures having cement and hydrated lime as filler material respectively. The mixtures with Portland cement and hydrated lime as substitution fillers have been used to evaluate the effect of substitution filler on the performance of asphalt mixture. Similarly, an asphalt binder having performance grade 58-22 with penetration grade 60/70 were used in the study. The basic properties of bitumen have been reported in Table 4.

Table 4. Properties of control binder

Sr. No.	Test Title	Standard	Bitumen type (Pen. 60/70)	Specification Limit
1	Flash and fire point (°C)	ASTM C 142	291	232 (min)
2	Softening Point (°C)	ASTM D 36	46	---
3	Ductility (cm)	ASTM C 88	100	100 (min)
4	Penetration at 25 °C (1/10th of mm)	ASTM D 5	70	---

For designing six asphalt mixtures, optimum bitumen content of 4.3% for Margallah aggregate and 4.8% for Sargodha aggregate minerals were determined from the Marshall mix design method [29]. A very little effect of filler substitution was found on asphalt content. In this study, the optimum bitumen content of 4.3% for Margallah aggregate and 4.8% for Sargodha aggregate minerals was fixed for all mixtures. Portland cement and hydrated lime were taken from locally available sources. Some basic properties of cement and lime are given in Table 5.

Table 5. Properties of Substitution Fillers

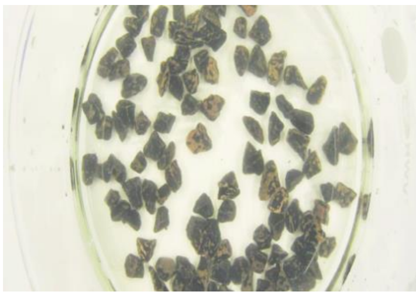
Specific Property Name	Standard	Portland Cement	Hydrated Lime
Density (Ib/cu in)	ASTM D792	0.1139	0.084-0.973
Specific Heat ($JK^{-1}Kg^{-1}$)	ASTM E1269	1554	913
Water Absorption (%)	ASTM D570	0.05-0.08	0.975
Specific gravity	ASTM D891	3.16	2.4-2.7
Tensile strength (psi)	ASTM D638	300-700	138.78
Thermal Conductivity ($W\ m^{-1}K^{-1}$)	ASTM E1952	1.17	1.26-1.4
Melting Point (°C)	ASTM D1519	1450	2574

2.2. Sample Preparation

For four performance tests (APA, FPBB, DM, and RBT), samples were prepared according to their standard procedures. 7 kg aggregate samples were compacted for asphalt pavement analyzer and dynamic modulus by considering the procedure postulated in AASHTO PP 35.

FBBT sample

DM test sample



RBT sample

Figure 4. Prepared Samples

Similarly, roller compacted slabs were prepared for the FPBB test. The limits of air voids in compacted samples were kept at 6±0.5%. The temperature of the mixture for mixing and compaction purposes was kept at 160±3^{o}C and 150±2^{o}C respectively. For the rolling bottle test, the particles passing sieve no.9.5 and retained on sieve no. 6.3 were selected. The description and dimensions of used samples are given in Table 6.

Table 6. Description and sample sizes

Test Description	Standard	Sample dimension/Size	Air voids (%)
Asphalt Pavement Analyzer (APA)	AASHTO TP 63	• Diameter 150 mm • Height 75 mm	6.03
Dynamic Modulus Test (DM)	AASHTO TP 62	• Diameter 100 mm • Height 150 mm	6.1
Four Point Bending Beam (FPBB)	AASHTO T 321	• (380×63×50) mm	6.04
Rolling Bottle Test (RBT)	BS EN 12697	Particle passing sieve no.9.5 and retained on sieve no.6.3	---

Some volumetric properties of asphalt mixture with treated and untreated fillers are summarized in Table 7.

Table 7. Hot mix asphalt design volumetric properties

Mix Type	Aggregate type	OBC	VA	VMA	VFA
Standard	ASTM D3515	ASTM D6307	---	ASTM D6995	---
Specification Limit	---	---	04 to 07	14 (Minimum)	65-75
Conventional Mix	Calcium carbonate	4.3	6.1	15.53	60.95
	Dolerite	4.8	6.0	15.85	62.30
Lime as Filler	Calcium carbonate	4.3	6.1	16.61	63.29
	Dolerite	4.8	6.0	17.32	65.57
Cement as Filler	Calcium carbonate	4.3	6.1	16.54	62.92
	Dolerite	4.8	5.7	17.42	67.50

Super-pave gyratory compacted samples were cut into two pieces and get the required standard height for asphalt pavement analyzer. Similarly, roller compacted slabs were fabricated into the required dimensions.

3. Results and Discussion

3.1. Rut Performance of Asphalt Mixture

Rutting performance of asphalt mixtures was evaluated with the asphalt pavement analyzer. Different computer-operated equipment with temperature control chambers are used in the laboratory for performance measurement of asphalt mixtures at the approximately same condition to that in-service pavement. APA is multifunctional testing equipment used to predict the performance of hot mix asphalt (HMA) and simulate it with field performance. Super-pave gyratory compacted samples with 150mm diameter and 75mm height were loaded with a steel wheel of 100 lb. which resting on a pneumatic hose with 100 psi pressure. Rutting test was conducted at 55^{o}C in accordance with AASHTO TP 63. The obtained results are given in Figure 5.

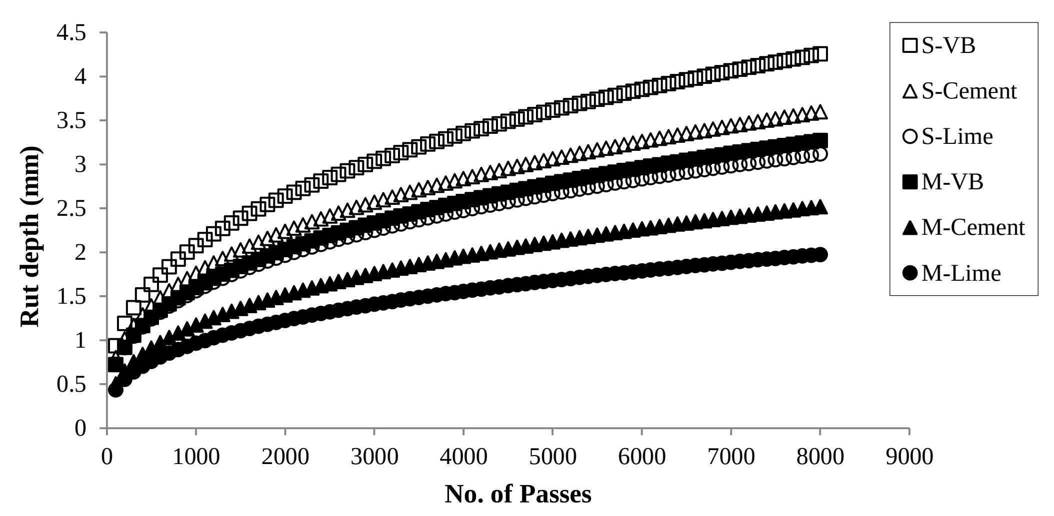


Figure 5. Asphalt Pavement Analyzer test results

Figure 5 illustrates the evaluation of rut depth against a number of wheel passes according to standard laboratory test conditions and clearly mentioned the improvement of rut resistance of mixture with substitute fillers as compared to mixtures with untreated fillers. The figure shows that rut depth increases with an increase in a number of wheel passes for all mixes. The Sargodha aggregate, containing dolerite minerals, without substitution filler have maximum rut depth against 8000 wheel passes as compared to Margallah aggregate containing Calcium carbonate minerals. All at once, when the cement and hydrated lime fillers were introduced into asphalt mixture, the rut depth values considerably decreases. It also has been noted from figure that when hydrated lime was used as filler material, dolerite minerals have less rut depth as compared to Calcium carbonate minerals. Similarly, cement and hydrated lime as substitution filler have a considerable effect on rut depth and improve the resistance against permanent deformation for all types of mixtures.

3.2. Dynamic Modulus

Two main components are typically described such as phase angle (δ) which gives elastic and viscous behavior of bituminous mixture and dynamic modulus which give material stiffness under different loading frequency and temperature conditions. The dynamic modulus is typically defined as "the ratio of the amplitude of sinusoidal stress at any given loading frequency and time to the sinusoidal strain at given the same frequency and time condition. Dynamic modulus $|E^*|$ is one of the important property of bituminous mixture for prediction of pavement performance under different temperature and frequency conditions. The behavior of temperature-time dependency of hot mix asphalt (HMA) is usually defined in the laboratory determine dynamic modulus. Due to changing frequency and temperature dependency, it is very difficult to compare results across varying frequency and temperature conditions. For this, a master curve is developed for meaningful comparison. Master curves is a means to obtain a visual representation of results taken from different frequency and temperature conditions [30]. For testing prepared specimens, four temperatures (4.4, 21.1, 37.8 and 54.4) and six frequencies (25Hz to 0.1Hz) were used. The test was performed in accordance with AASHTO TP 62. The master curve results are given in Figure 6.

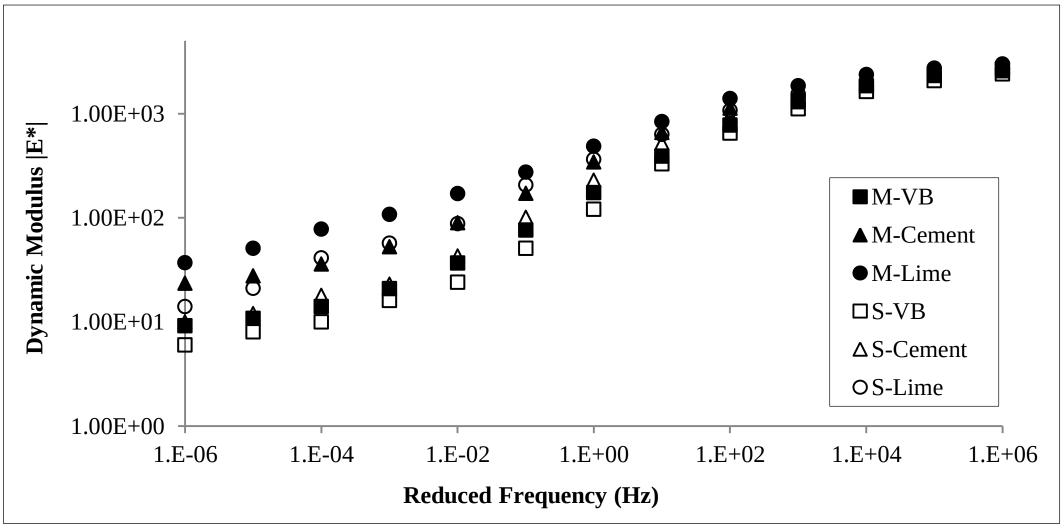


Figure 6. Master curve of all mixes

Figure 6 shows the evaluation of dynamic modulus against reduced frequency at standard test condition and clearly observed that dynamic modulus increased with the introduction of cement and hydrated lime as substitution filler. A calcium carbonate mineral with hydrated lime as filler shows maximum dynamic modulus at both, high temperature, low-frequency condition and low temperature, high-frequency condition. The utilization of hydrated lime as filler in asphalt mixture has more significant beneficial effect on dynamic modulus as compared to cement filler.

3.3. Fatigue Performance of Mixture

Four-point bending beam (FPBB) test is used for the measurement of fatigue damage or stiffness loss of hot mix asphalt material during repeated loading. Fatigue is considered an important parameter during designing the purpose of asphalt pavement. The test was performed in stress control mode in accordance with AASHTO T 321. The temperature of the test chamber was set at 20±0.5°C. The beam was considered as a failure when 380mm long and 63mm wide by 50mm thick HMA specimen reduce its 50% initial stiffness. The failure energy and fatigue life of hot mix asphalt were determined under repeated load conditions. The test results are given in Figure 7.

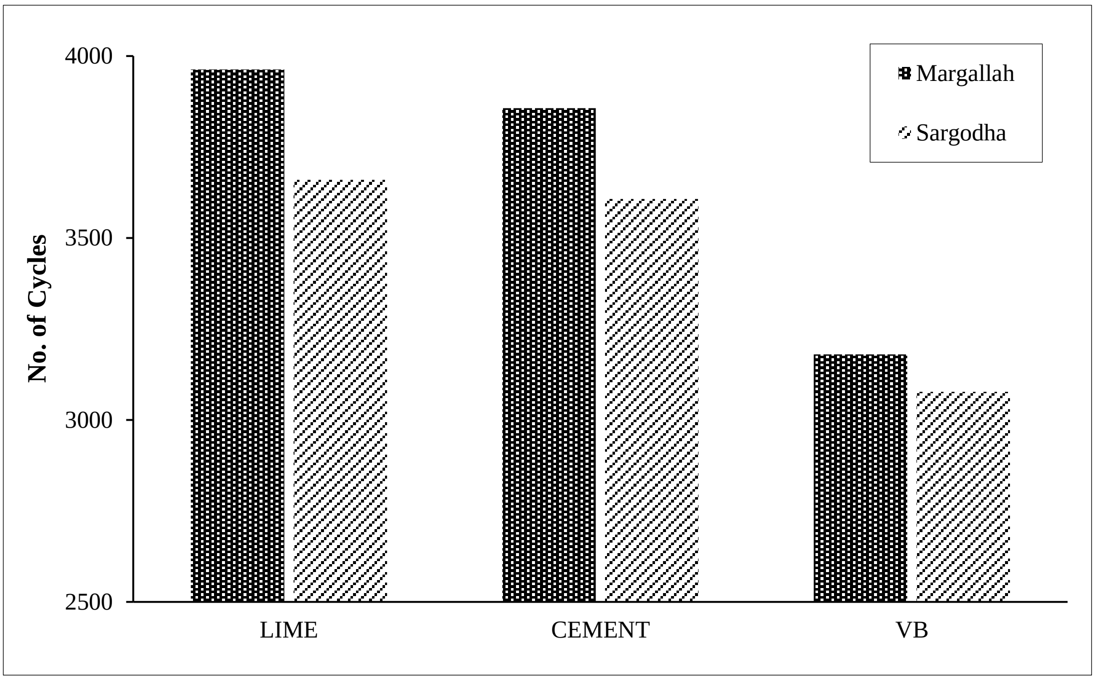


Figure 7. Fatigue life of the mixes

It can be observed from Figure 7, Calcium carbonate minerals with hydrated lime as filler material show maximum resistance against fatigue cracking at standard test conditions. Both cement and hydrated lime as substitution filler improves the fatigue performance as compared to conventional asphalt mixture. Like the previous results, hydrated lime as a substitute filler gives better performance as compared to cement.

3.4. Adhesion Performance of Mixture

Adhesion properties of the mixes were evaluated by using a rolling bottle test (RBT). RBT is used to measure the aggregate-bitumen coating vulnerability after mechanical abrasion under-water. Rolling bottle test is a visual inspection test from which the remaining covering of aggregate-bitumen coating is estimated. The test was performed in accordance with European standard BS EN 12697. Three replicates of each mixture were rotated with a stirrer in the bottle for 72 hours with 60 rotations per minute and note reading after 6, 24, 48, and 72h. The results are discussed in Figure 8.

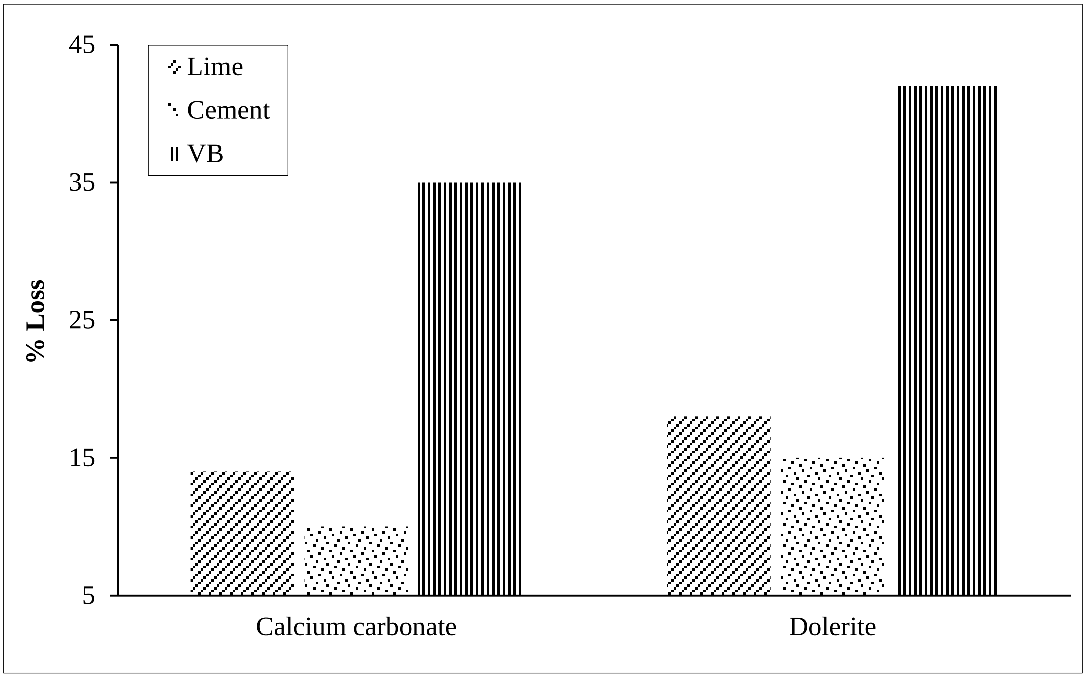


Figure 8. Effect of moisture after 72h

Figure 8 shows the evaluation of % loss of bitumen covering from aggregate at standard laboratory test conditions. The presence of substitute fillers in asphalt mixture significantly reduces the % loss of aggregate-bitumen cover and improves the adhesion properties of the mixture. Both cement and hydrated lime as substitution filler improves the adhesion of the mixtures. Contrary to previous results, cement gives better results as compared to hydrated lime for adhesion properties of the mixtures.

3.5. Summary and Discussion

The overall trends of substitution fillers on the performance of asphalt mixture are summarized in Table 8. The table was generated by using the experimental test results and the following thoughts: "what is the most likely trend obtained from performance-based test results?" The size of the arrows indicates the importance of parameter on the performance of asphalt mixture. Larger size arrow indicates higher impact and smaller arrow size indicate the lower impact of substitute filler on HMA performance.

Table 8. Performance based indication of asphalt mixture

Mixture Type	Rutting resistance	Fatigue resistance	Dynamic modulus	Moisture susceptibility
Calcium carbonate minerals with cement filler				
Calcium carbonate minerals with hydrated lime filler				
Dolerite minerals with cement filler				
Dolerite minerals with hydrated lime filler				

Legend:

More beneficial effect = 

Less beneficial effect = 

The overall performance of substitute fillers in Table 8 shows that all the mixes improve rutting and fatigue resistance, visco-elastic behavior, and resistance against moisture susceptibility from its conventional mixes. Hydrated lime as a substitute filler has more beneficial for rutting and fatigue resistance as well as for visco-elastic behavior. Similarly, cement as a substitute filler in the mixes has more favorable for resistance against moisture damage.

4. Conclusion

Overall, in this research study, two substitution fillers (cement & lime) were used with two different aggregate quarries (based on minerals composition) to evaluate the relatively most beneficial combination of both fillers as well as an aggregate quarry to enhance the performance life of asphalt pavements, especially in under-developed countries. Four basic tests (Asphalt Pavement Analyzer, Four Points Bending Beam, Dynamic Modulus, and Rolling Bottle Test) that test the most desired properties of any asphalt pavement were utilized to access the performance properties of modified asphalt mixture. Based on all laboratory test results, it is concluded that replacement of filler with cement and hydrated lime improves the fatigue, adhesion, and rut performance of asphaltic concrete mixture up to 25%, 70%, and 25% respectively to that of the conventional mixture.

However, cement as substitution filler in asphalt mixture has a comparatively more beneficial effect on permanent deformation and fatigue performance in comparison with lime. While cement substitute (as filler) enhances the adhesion properties (moisture resistance) of asphalt mixture. Cement has a relatively stronger bond with calcium carbonate aggregate quarry, while lime substitute filler has a more compatible bond with dolerite type aggregate quarry.

5. Acknowledgements

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6. Conflicts of Interest

The authors declare no conflict of interest.

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