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Analysis of Fillers to Assess the Hot Mix Asphalt Performance: Sugar Cane Bagasse

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Abstract

Constructing adequate amount of infrastructure has a positive influence on the economic growth of a nation. Roads are also a type of infrastructure that is incessantly constructed to meet the vehicles demand of new roads. Consequently, the need of the hour is to construct structurally sound pavements with an acceptable level of comfort. This study used an agricultural debris known as Sugarcane Bagasse Ash (SCBA) as a filler to study its effect on the performance of Hot Mix Asphalt (HMA). Methodologically, the evaluation of SCBA was performed using Indirect Tensile Strength (IDT) and Marshall Stability tests. The results show that the stability of 8.78 KN and 10.31 KN was obtained when SCBA and stone dust was incorporated in virgin HMA and at Optimum Binder Content (OBC) of 4.55 % and 4.33 % respectively. After passing 14,000-wheel tracker cycles on SCBA and stone dust samples at 30 ^{0}C resulted in average rut depth of 1.97 mm and 2.30 mm. however, these results changes significantly when the samples were tested at temperature 60 ^{0}C. In case of SCBA, the rut depth was calculated as 7.63 mm, meanwhile, a rut depth of 6.15 mm was recorded in the samples containing stone dust. IDT results indicated that this filler possess a decent resistance against freezing and thawing based on its strength of 6.7 %. To recapitulate, this filler has satisfactory tensile strength at lower temperatures. It is recommended that SCBA should be incorporated for the manufacturing of HMA in low-temperature areas.

Index Terms: *Rutting, Hot Mix Asphalt, Sugarcane Bagasse Ash, Filler, Temperature.*

I. INTRODUCTION

Various modes of transportation have significant role in the economy and national GDP of a country. The roads system of Pakistan has an utmost influence on the freight transportation both at national and foreign trade. Due to the geographic position of Pakistan in South Asia, it is connected to the innumerable sea-ports like Gwadar Port and Port Qasim. The roads network in Pakistan is not only limited to its own benefit, but it is also the only way of trade to the landlocked country Afghanistan, therefore, making it necessary to have unyielding and adequate pavement strength is necessary for the smooth operation of cargo transportation. The highways of Pakistan are regarded as the only means of oil and petroleum transportation from Middle East. The smooth entry and egress of long-haul vehicles depend on the quality of pavements. Higher the quality of pavements, higher will be the comfort level and lower will be the prices of shipments, which will ultimately boost the economy. According to the known literature, there are two types of pavements namely Flexible and Rigid pavements. Flexible pavements have low-initial cost and high maintenance cost as compared to rigid pavements. Hence, a suitable flexible pavement should be adopted with modified properties that could fulfil the requirements of cargo transportation

Rutting is a category of major distress that is formed when a permanent deformation occurs due to cyclic loads, which can easily be seen in the form of wheel paths engraved on the Hot Mix Asphalt (HMA) pavements [1]. It has been estimated that the major causes of rutting include weak asphalt mixtures, inadequate compaction, and reduced pavement thickness [2]. Some experts believe that the answer for rutting lies in the HMA layers [3-5]. In another study, it was found that rutting is a result of structural flaw [6]. Similarly, it has been estimated that the performance of HMA is significantly changed with variation in air voids i.e., voids percentage below than 3 % lowers the performance of HMA, which results in rutting. On the other hand, the deformation is considerably reduced, when a higher percentage of air voids are present in the HMA [7].

The effect of variation of aggregate gradation on asphalt concrete mix properties was also analyzed [8].

The objective of this study was to assess the effects of fillers when it is used in HMA and how much the fillers would alter the virgin HMA properties. As this study used Stone Dust (SD) and Sugar Cane Bagasse Ash (SCBA), therefore, the testing sample were compared at 30 ^{0}C and 60 ^{0}C.

II. LITERATURE REVIEW

A. Rutting Due to Compaction

This is one a major reason, which results in rutting. Due to over-compaction and under-compaction of pavement layers and not conforming to the design limits results in permanent deformation. When these roads are opened to normal traffic, compaction takes place irregularly, hence, it leads to rutting. It was stated in a recent study that reduced compaction often influences the central and bottom most layers; moreover, the rut depth is also determined the degree of compaction [9].

B. Shear Deformation Resulting in Rutting

This phenomenon occurs when heavy traffic is allowed on the road for which the road is not designed. This results in disruption and segregation of asphaltic materials. Also, heavy- and slow-going traffic would result shear failure.

C. Advances in Improving the Quality and Rut Resistance Power of HMA

Myriad of scientists and researchers have conducted an innumerable number of studies to ameliorate the resistance attribute of HMA by the addition of new additives of diverse materials and novel approaches. In this regard, a plethora of procedures have been undertaken to make use of agriculture and manufacturing wastes to improve the resistance of HMA.

In many agricultural countries like Pakistan and India, agriculture is considered a major sector and that is the reason that most household depend on this sector for their livelihood. Since this is a huge sector, it generates a gargantuan proportion of debris. If this waste is not recycled, it would ultimate prove hazardous to all the living creatures, hence, this waste can be used a filler in HMA [10].

The principal reason for adding filler in binder is that it immensely increase the adhesion properties in aggregates and binder [11].

A study was conducted to assess the influence of filler, binders, and aggregates in providing the strength to the asphaltic pavements. It was found that filler acts as an inert material and has promising results in proving stiffens to the HMA [12].

In a recent research, it was stated that recycling and reuse of waste products like agricultural biomass pave way for new technology along with clean-environment [13].

Various tests were conducted on a wide variety of domestic and industrial waste using as a filler with other binders in HMA. The results showed that the addition of fillers increase the durability of pavement layers along with embankments [14].

Some other researchers used bagasse ash as a filler and they found that it reduces the amount of methane emission and also the pavement performance is significantly improved [15].

It was concluded in a study that the particle size of of SCBA should be reduced to improve its properties when it is added as a filler in various materials [16].

Moreover, the SCBA has amorphous Silicon Dioxide ($SiO2$), it combines with the carbon, which reduces the environmental pollution. This is the fundamental reason that stone dust is used in combination with SCBA as a filler in HMA [17-19].

III. MATERIAL AND METHODS

The material used in this research work is classified in to bitumen, aggregates and filler material. The samples of the bitumen were collected from an Attock Oil Refinery in Pakistan and it has a penetration grade of 60/70.

The aggregate (coarse, fine and stone dust) was collected from stalk piles of Margalla Hills and sugar bagasse ash which were used as filler material as a modifier were collected from various sources of agricultural lands and sieved from No.200 standard sieve. Table 1 shows the classification of the attributes of bitumen like specific gravity, penetration test of bitumen and ductility.

The following tests were conducted to know the chemical composition of these HMA:

Table 1: Characteristics of Bitumen

Test Description	Results
Penetration	70
Flash Point (^{0}C)	259.66
Fire Point (^{0}C)	287.33
Ductility (Cm)	86.66
Softening Point (^{0}C)	55.5

Table 2 shows the evaluation of the properties of aggregate, the tests like Fineness Modulus (FM), specific gravity of filler and SD, abrasion and impact value tests, and gradation of materials.

Table 2: Aggregate Lab Test Results

Test Descriptions	Results	Limits
FM of Coarse Aggregate	4.54	=3 or Greater
FM of Fine Aggregate	3.019	2.3 up to 3.1
Average Impact Value	16.84 %	10 up to 20
Los Angeles Abrasion Test Result, Average Percentage Loss	29.09%	<40% for Wearing Coarse
Specific Gravity of Coarse Aggregate	2.69	
Apparent Specific Gravity of Coarse Aggregate	2.7	
Specific Gravity of Filler Stone Dust	2.66	
Apparent Specific Gravity of Fillers Stone Dust	2.72	

After the performance of these basic tests on bitumen, aggregate and fillers all the results were according to limit and specification and our material was best for use in the HMA.

A. Marshall Test

Marshall Tests were performed on conventional and nonconventional samples to get optimum bitumen content for performing main tests of this research which is Wheel Tracker test and Optional tests which are freezing and thawing effect measurement through Marshall Molds and Ultrasonic Pulse Velocity test which is a nondestructive test.

Table 3 shows the results of Marshall samples of 3.5, 4, 4.5, 5, 5.5 and 6 percent bitumen was taken by weight of total sample weight of 1200 grams. However, the only difference between conventional and non-conventional sample is that of filler material, which is used in such a way that in conventional samples SD was used.

Table 3: Marshal Result for Conventional Marshall Samples (Stone Dust Filler)

Binder Content	G mb	G mm	Av (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	Unit Weight/ Density (g/cc)
3.5	2.32	2.56	9.36	15.3	39.0	9.43	2.47	2.32
4	2.35	2.55	7.67	14.5	47.3	10.0	2.55	2.35
4.5	2.38	2.48	3.74	13.8	72.8	9.32	2.83	2.38
5	2.40	2.49	3.58	13.7	73.9	8.09	2.98	2.40
5.5	2.44	2.52	3.17	12.8	75.2	7.87	3.10	2.44
6	2.43	2.51	3.18	13.6	76.6	6.71	3.47	2.43

Whereas, Table 4 shows the results of non-conventional samples of SD having fully replaced SCBA.

Table 4: Marshal Result for Modified Marshall Samples (SCBA Filler)

Binder Content	G mb	G mm	Av (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	Unit Weight/ Density (g/cc)
3.5	2.34	2.55	8.23	14.63	43.7	7.13	2.09	2.34
4	2.34	2.52	7.33	14.99	51.0	8.78	2.14	2.34
4.5	2.37	2.51	5.78	14.44	59.9	8.29	3.63	2.37
5	2.39	2.53	5.37	13.87	61.2	7.9	3.84	2.39
5.5	2.43	2.53	4.09	12.99	68.4	6.27	4.02	2.43
6	2.43	2.53	3.92	13.46	70.8	6.44	4.12	2.43

Based on the results of the Table 3 and Table 4, the following graphs (Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6) were obtained:

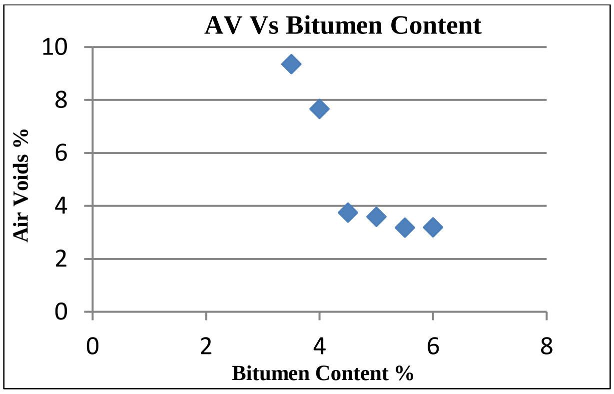


Figure 1: Percentage Air Voids of Conventional Sample

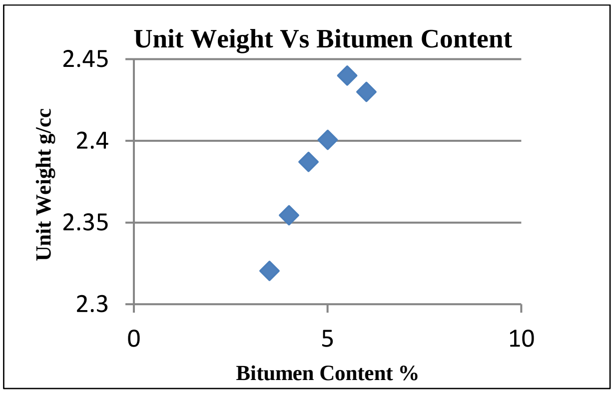


Figure 2: Unit Weight of Conventional Sample

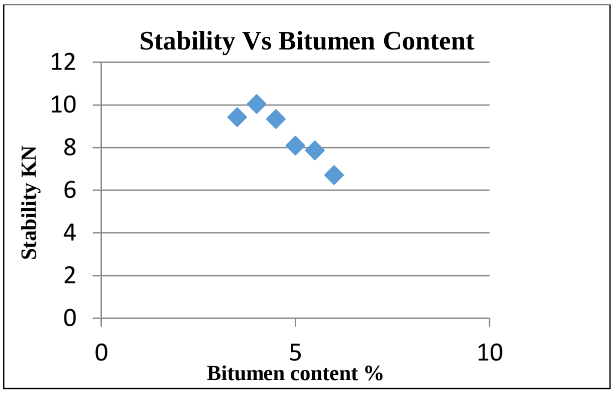


Figure 3: Maximum Stability of Conventional Sample

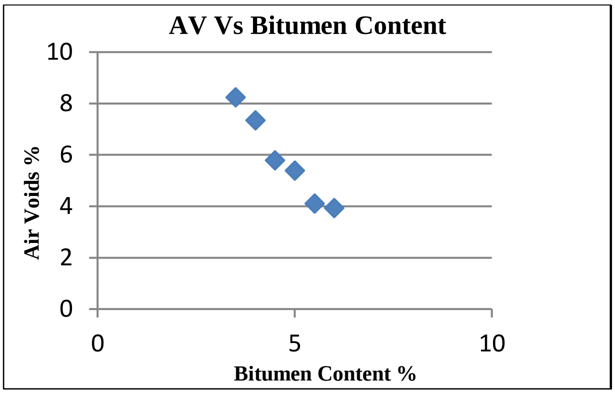


Figure 4: Percentage Air Voids of Modified Marshall Samples

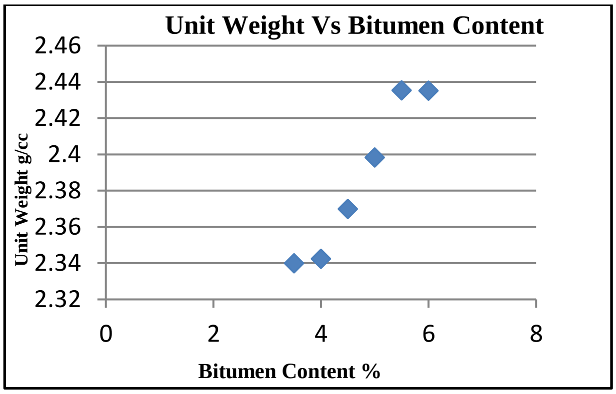


Figure 5: Unit Weight of Modified Marshall Samples

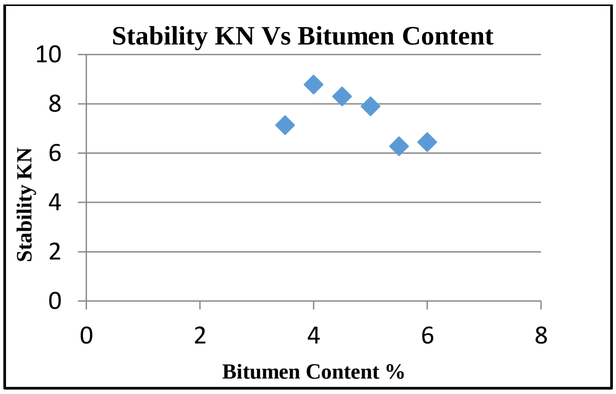


Figure 6: Maximum Stability of Modified Marshall Samples

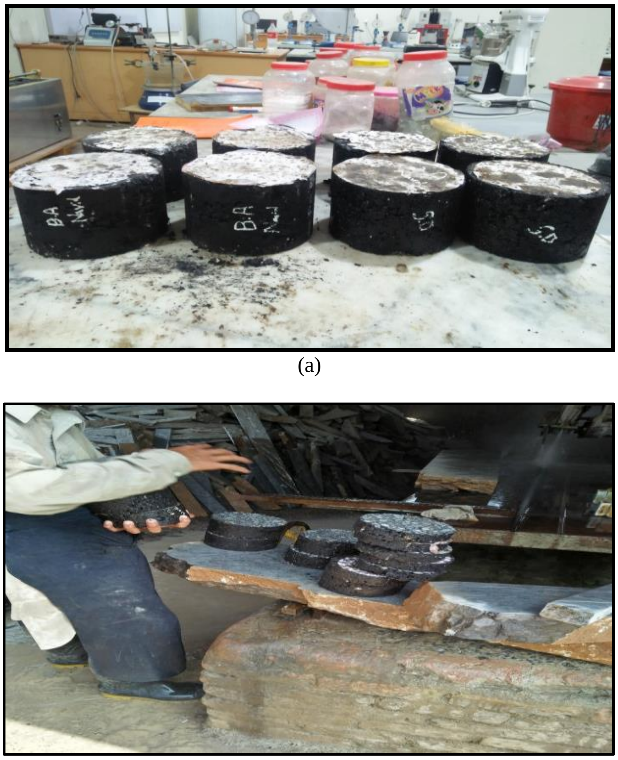
Hence, the Optimum Binder Content or OBC was calculated using Eq. (1) as shown below:

$$\text{OBC} = \frac{\text{Air voids+ Unit weight+ Max Stability)}}{3} \qquad (1)$$

The OBC values for the conventional and nonconventional samples were calculated by the above formula i.e., 4.33 and 4.55 percent respectively.

B. Wheel Tracking (WT) Test

Wheel Tracker (WT) test was conducted for finding out the rut resistance of HMA samples which were modified by using SCBA as a filler material. The comparison was made between conventional samples having filler as stone dust and nonconventional samples consisting of SCBA passing through No.200 standard sieve. The specimen of WT consisted of 6in in diameter and 3in in height. The figures below show the sample before and after trimming by cutter for placement in Marshall Machine.
The following figure i.e., Figure 7 (a) and 7 (b) illustrates the Marshall samples, which were prepared for the test:



(a)

(b)

Figure 7: (a) Samples Prepared (b) Samples Trimmed for the Test

The Table 5 indicates the selection of specimen and its specifications. A total of 6 specimen were selected for WT testing, 3 specimens were based on SCBA and SD at 30 ^{0}C and 3 specimens were selected at 60 ^{0}C for SCBA and SD.

Table 5: Wheel Tracker Samples Description

Selected Temperature	SD Specimen	SCBA Specimen	Combined Specimen
30 ^{0}C	3	3	6
60 ^{0}C	3	3	6

Based on the results of WT, it is evident that rut depth increases with the increase in number of passes. However, as evident from the Figure 8, there is no significant change in rutting. It can also be seen that SD rutting depth is higher than the SCBA at 30 ^{0}C.

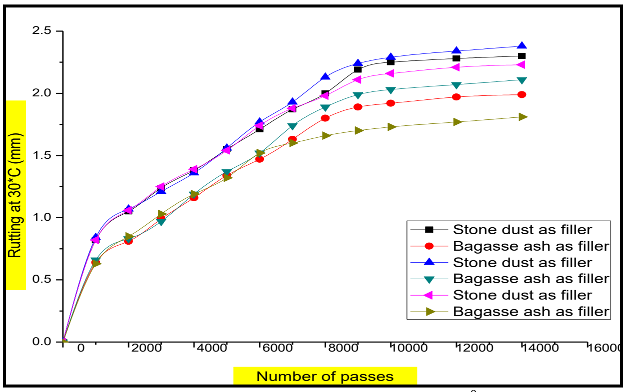


Figure 8: Specimen Results Plot at 30 ^{0}C

Table 7 shows the results of WT test that was conducted on 6 specimens of SD and SCBA as filler at 60 ^{0}C. Clearly, it can be seen that the specimens containing SD have low rut depth as compared to the specimens containing SCBA as fillers.
Table 6 shows the results of WT test. It shows that the rut depth increases with the increase in number of passes at 30 ℃ in both the filler SD and SCBA.
Table 7 shows the results of WT test that was conducted on 6 specimens of SD and SCBA as filler at 60 ^{0}C. Clearly, it can be seen that the specimens containing SD have low rut depth as compared to the specimens containing SCBA as fillers.
From the results of Table 6 and Table 7, it is evident that different samples have different role in strength of performeance of asphaltic pavements.
The comparison of standard and SCBA samples were performed. Both the samples were tested for 14000 number of passes. The corresponding numebr of passes and the rut depth of each sample was noted.
Table 6 illustrates that at 1000 passes, the rut depth of SD is higher than the rut depth of SCBA at 30 ^{0}C. Also, the rut depth at 5000 passes of SD was higher than SCBA in all the selected samples. Similarly, at 10000 passes, the rut depth in all SD samples were 2.1-2.2 mm while the rut depth of SCBA was between 1.7-2.1 mm. This means that SCBA performs better than SD on lower temperatures.
However, in Table 7, the comparison of SD and SCBA at 60 ^{0}C shows that at 1000 passes, the rut depth ranged from 1.1-2.2 mm, meanwhile, SCBA rut depth was 2.47-2.5 mm. At 10000 passes,the SD depth was 4.87-6.09 mm as compared to 6.91-8.99 mm in SCBA. This means that SCBA does not perform at higher temperatures.
Figure 9 shows the when SD was used a filler in HMA at 60 ^{0}C, the rut depth was significantly lower than the specimens containing SCBA at 60 ^{0}C. However, in one sample of SCBA, the rut depth was lowest as compared to rest of 5 samples and on the same time the SCBA filler was found to experience highest rut depth. Hence, it is clear that SD can confidently be used at high temperature areas as the rut depth is lower in HMA.

Table 6: WT Test Outcomes at 30 ^{0}C

No. of Passes	Rut Depth at 30 ^{0}C of Stone Dust Filler Sample 1	Rut Depth at 30 ^{0}C of Stone Dust Filler Sample 2	Rut Depth at 30 ^{0}C of Stone Dust Filler Sample 3	Rut Depth at 30 ^{0}C of Bagasse Ash Filler Sample 1	Rut Depth at 30 ^{0}C of Bagasse Ash Filler Sample 2	Rut Depth at 30 ^{0}C of Bagasse Ash Filler Sample 3
0	0	0	0	0	0	0
1000	0.82	0.84	0.82	0.64	0.66	0.63
2000	1.05	1.07	1.06	0.81	0.83	0.85
3000	1.24	1.21	1.25	0.99	0.97	1.03
4000	1.38	1.36	1.39	1.16	1.19	1.19
5000	1.55	1.56	1.54	1.34	1.37	1.32
6000	1.71	1.77	1.74	1.47	1.52	1.52
7000	1.87	1.93	1.88	1.63	1.74	1.6
8000	2	2.13	1.98	1.8	1.89	1.66
9000	2.19	2.24	2.11	1.89	1.99	1.7
10000	2.25	2.29	2.16	1.92	2.03	1.73
12000	2.28	2.34	2.21	1.97	2.07	1.77
14000	2.3	2.38	2.23	1.99	2.11	1.81

Table 7: Wheel Tracker Result Data for 60 ^{0}C

No of Passes	Rut Depth at 60 ^{0}C of Stone Dust Filler Sample 1	Rut Depth at 60 ^{0}C of Stone Dust Filler Sample 2	Rut Depth at 60 ^{0}C of Stone Dust Filler Sample 3	Rut Depth at 60 ^{0}C of Bagasse Ash Filler Sample 1	Rut Depth at 60 ^{0}C of Bagasse Ash Filler Sample 2	Rut Depth at 60 ^{0}C of Bagasse Ash Filler Sample 3
0	0	0	0	0	0	0
1000	2.21	1.17	2.22	2.55	2.55	2.47
2000	2.87	2.03	2.81	3.35	3.14	3.21
3000	3.46	2.37	3.43	3.82	3.69	4.11
4000	3.79	2.79	3.84	4.27	4.24	4.79
5000	4.4	3.11	4.31	4.77	4.75	5.31
6000	4.87	3.57	4.61	5.44	5.38	5.77
7000	5.44	3.9	5.08	5.98	5.87	6.23
8000	5.85	4.43	5.73	6.47	6.47	6.84
9000	5.97	4.69	6.35	6.81	6.76	7.56
10000	6.09	4.87	6.79	6.99	6.91	8.17
12000	6.2	5.02	6.91	7.06	7.03	8.48
14000	6.31	5.13	7.03	7.13	7.11	8.65

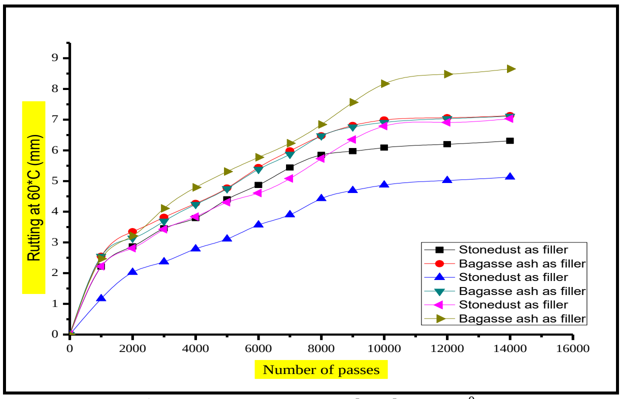


Figure 9: Specimen Results Plot at 60 ^{0}C

IV. RESULTS AND DISCUSSION

Marshall specimen were made with the addition of SD and SCBA. Each filler was divided into 3 specimens and tested at 30 ^{0}C and 60 ^{0}C. Afterwards, WT specimen were made with adequate OBC and were also tested at 30 ^{0}C and 60 ^{0}C. Hence, the rut depth was calculated using number of passes. Hence, the following observations were obtained.

A. Performance Test Results

After comparing the testing results, it was found that SD achieved the flow of 3.47 mm and stability of 10.04 kN was obtained. Similarly, in case of SCBA, the flow of 4.12 mm was observed along with a stability of 8.78 kN. Hence, highest stability was achieved by the SD and the highest flow was attained by SCBA specimen.

B. Wheel Load Test

Since, the technological development is moving with fast pace, a quick and robust method should be employed. The WT test is an essential method for estimating the rut depth based on the number of cycles. The WT results indicate that when SCBA is used as a filler at 30 ^{0}C, the pavement resistance improved significantly as compared to SD. It was also found that at the same temperature, rut depth was recorded as 1.97 mm and 2.31 mm was recorded in SCBA and SD respectively. These reading were different when the samples were tested at 60 ^{0}C. At this temperature, the SCBA rut depth and SD rut depth was noted as 7.63 mm and 6.15 mm respectively.

V. CONCLUSION

OBC increased up to 5 % (4.33 to 4.55) as compared to the OBC of conventional Marshall Sample. The following conclusion were made:

- It was concluded that the Marshall Stability of specimen containing filler dwindled to 12.47 % as compared to maximum conventional Marshall Sample's stability.
- It was also concluded that based on results in the WT test that at 30 ^{0}C, there was highest resistance measured in terms or rutting, which was 14.47 % lower than the virgin samples. However, at 60 ^{0}C, the virgin specimen performed will in terms of rut resistance and measured as a percent change of 19.39 %.

VI. FUTURE RECOMMENDATIONS

Based on the conclusion, it is recommended that SCBA and SD should be used in filler at low temperature areas, as it is environment friendly material and found in abundance, they should be used a filler in HMA to improve the pavement performance. As this study used dry specimen of HMA, further research can be conducted on submerged specimen to evaluate the other characteristics of HMA like resilient modulus and fatigue resistance.

Additionally, the use of SCBA should be also be assessed under dry and wet situation whether the filler can act as a stabilizing material in the subgrade.

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Authors Contributions

Naveed khan contribution to this study was the concept, data collection, and supervision. Muhammad Babar Ali Rabbani performed data curation, methodology, asphalt samples, project administration, and paper writing. Sameer Ahmed Mufti performed the validation, wheel tacker readings, and laboratory equipment. Noman Khan contributed in arranging and transporting the materials and figure sketching of the results.

Conflict of Interest

There is no conflict of interest between all the authors.

Data Availability Statement

The testing data is available in this paper.

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