Rutting Performance of Hot Mix Asphalt Using Bagasse Ash as Filler

Naveed Khan¹, Fazli Karim¹, Qaiser Iqbal¹ and Ayed Eid Alluqmani²

¹Department of, Sarhad University of Science and Information Technology, Peshawar, Pakistan
²Department of, Islamic University of Madina, Madina, Saudi Arabia

Correspondence Author: Naveed Khan (engrnaveedkhan01@gmail.com)

Received December 23, 2019; Revised September 03, 2021; Accepted September 13, 2021

Abstract

Highways play a pivotal role in the social and economic development of a country. Due to the increase in population, new highways are built every year to fulfill traffic demands. For this purpose, the demand is not only to have widened pavements with a high level of comfort but also to have structurally stable pavements thereby incorporating adequate materials in the pavement structure. In the present study, sugarcane bagasse ash (SCBA) which is an agricultural waste was used as a filler material in hot mix asphalt to check the effect on performance as per the Marshall Method of mix design with Marshall Stability, Rutting Resistance and Indirect Tensile Strength (IDT) as target parameters. The Marshall samples having bagasse ash (BA) used as filler in the mix design process has given maximum stability of 8.78 KN at optimum binder content (OBC) of 4.35%. While the Marshall samples having stone dust used as filler material in the mix design process gives maximum stability of 10.031 KN at OBC of 4.33%. Wheel tracking test samples having bagasse ash used as filler in mix design has given the best result at the temperature of 300°C and the average rut depth was recorded as 1.97 mm while wheel tracker samples having stone dust used in mix design has given average rut depth of 2.303 mm at 300°C and the number of passes recorded was 14000 cycles. On the other hand, the wheel tracker samples were tested at a temperature of 600°C. The samples having bagasse ash used in mix design has given greater rut depth of 7.65 mm at 600°C as compared to stone dust mix design samples with a measured rut depth of 6.15 mm. Indirect Tensile test modified samples having bagasse ash used as filler showed good resistance to freezing and thawing effects having a maximum average tensile strength of 6.7%. From the above-average results, it is concluded that bagasse ash is a better filler material as compared to stone dust when used as filler. Therefore, bagasse ash is recommended modifier filler to be used in asphalt mixtures for adequate rutting performance at the low temperature of 300°C such as lower temperature regions.

Index Terms: Highways, Rutting, Filler Bagasse Ash, Wheel Tracker, Best Modifier.

I. INTRODUCTION

An effective and good transportation system plays a great role in the development of a country. Pakistan has a very good geographical and bilateral location. Pakistan is located in the middle of some important nations such as China is located to the North-East, Afghanistan and Iran are located to the West and West-South respectively, whereas India also shares a long-running border with Pakistan to the East. The Arabian Sea a great means of water transportation is located to the south of Pakistan and acts as a borderline between Pakistan and Kingdom of Saudi Arabia. Pakistan has built six seaports upon the Arabian Sea in which Karachi port, Gwadar port, and Muhammad Bin Qasim port are the biggest. Pakistan acts as a gateway of Asia. Goods from usually all the world come to these ports and then transported by the network of roads located all over the country. Same as the other sources of transportation of goods and passenger highways also play an important and main role in transportation. In the coming times, the highways in Pakistan will play a great role and prove itself as exit and suitable routes for the transportation of petroleum and gas from the Gulf countries to the entire world through Pakistan and in the result will strengthen the economy of Pakistan. The strategic importance of roads which are discussed above shows and proves that the roads of the country should be of high quality. Generally, there are two types of pavements flexible and rigid. Rigid pavement has high initial and maintenance costs there for flexible pavements are widely used because it is economical and having low construction and maintenance costs.

Rutting is major distress of pavement usually occurs in the wheel path due to the repeated traffic flow which causes movement of material in plastic flow form. Some research reports such as Button et al., (1991), Anani et al., (1992) clearly concluded that rutting is caused not only with the weak underlying layers of subgrade but the main source of rutting is the permanent deformation in the hot mix asphalt (HMA) layers. Ford, Jr states in his research that rutting is also greatly influenced directly by air voids. Pavements having a higher air void show some strength to rutting resistance while those having voids percentage lower than 3 is greatly subjected to rutting or permanent deformations. Vaitkusa and Kleiziene (2014) concluded that rutting may be described as flow, structural and as well as wear
rutting.

**A. Rutting Due to Compaction**

Compaction or densification is one of the important issues which cause rutting. When a pavement layer is over compacted from the required design limits and then opened to traffic. The traffic also helps in the compaction and then rut appears in the pavement. Inadequate compaction or the compaction less than the required limit also helps in the generation of rutting in the pavement in such a way that when the traffic is allowed it will work as a compacter and pavement distress will occur. Tao and Xiaoming (2012) states in his research that inadequate compaction can result in the lower and middle layer thickness which can cause high rutting in the pavement. The final rut depth is also the product of inadequate compaction.

**B. Rutting Due to Shear Deformation**

Heavy traffic loads may cause upheaval or disruption which is basically the displacement of material in the pavement. Slow-moving vehicles at intersection may greatly cause shear failure.

**C. Improvement in Rut Resistant Property of Pavement**

Researchers and scholars are in the race of improvement of the rut resistant property of pavement through various techniques and additives in the HMA mix. There is also a lot of work upon the usage of industrial and agricultural waste products and its usage in the HMA mix. Kumar and Upadhyay (2017). Agriculture is the main source of income not only in Pakistan but the whole world is involved with agriculture. Therefore a large amount of agricultural waste is produced as a by-product and if they were not treated or used in any product then it will be hazardous to the living environment.

Anna (2018) state in his research that for the agricultural waste proper treatment and reuse in the new production new technologies is developing which helps and keeps our planet clean from the pollution of these agricultural waste and also provides a clean living environment.

Kumar and Upadhyay (2017) present in there review publication that the utilization of biomasses and waste is necessary to gain economic values and also keep clean our living environment. These agricultural biomasses are widely used in our daily manufacturing products such as usage in the hot mix asphalt as a filler material, usage in the bricks making and also helps in the production of biogas. For more usage, more research is required upon agricultural waste materials.

Ormsby and Fohs(1980) during the period of 1970 to 1980 the Federal Highway Administration of US Transportation Department studied many waste materials from different sources such as domestic waste, metallurgical and industrial waste. Different waste materials such as coal mines refuse, sewerage sludge's, agricultural waste, rubber waste and the waste produced in the production of cement. These stated waste materials were then treated with different binders such as lime, fly ash or lime, bitumen and Portland cement respectively. A large number of laboratory and field tests were performed and its characteristics were studied. These modified materials when checked at laboratories and field give better strength and proved it suitable for the use in subgrade, sub-bases and other bases as well as suitable to be used in improvement in the embankments. Some materials results were good to be used in the pavement bitumen wearing coarse.

Martirena et al., (1998) stated that sugarcane bagasse ash is rich in silica content usually in a crystalline or amorphous state and having unburnt carbon and this is the reason to replace stone dust partially with bagasse ash as filler in asphalt. Mohammed and Amin (2009), Sirirat and Supaporn (2010) stated that methane emission takes place from organic materials by using bagasse ash as a filler we can not only reduce methane emission but compressive strength of asphalt pavement can also be improved.

Imam [2010] stated that usually binders are selected to improve the stiffness of binder mastic or to strengthen the bond of adhesion between binders and aggregate. Murana and Jegede (2013) stated that Asphalt concrete consists of aggregates, binders (Bitumen) and filler (usually stone dust). The filler is very fine inert mineral and plays an important role in asphalt to improve the density and strength of HMA.

**II. MATERIAL AND METHODS**

The material used in this research work is classified in to bitumen, aggregates and filler material. The bitumen of 60/70 penetration grade is collected from Attack Refinery Limited (ARL). Various tests were performed to characterize the Bitumen and its properties which results are tabulated in table form as under. The aggregate (coarse, fine and stone dust) were collected from stalk piles of Margalla Hills and sugar bagasse ash which were used as filler material as a modifier were collected from own agricultural land and sieved from No.200 standard sieve. All the results such as specific gravity, penetration test of bitumen, gradation of material of material are stated in the table below:

**Table I: Characteristics of Bitumen**

| Test Description | Results    |
|------------------|------------|
| Penetration      | 70         |
| Flash Point (°C) | 259.66     |
| Fire Point (°C)  | 287.33     |
| Ductility (Cm)   | 86.66      |
| Sothening Point (°C) | 55.5       |
| Specific Gravity | 0.962      |

**Table II: Aggregate Lab Test Results**

| Test Descriptions                  | Results | Limits                   |
|------------------------------------|---------|--------------------------|
| Fineness Modulus of Coarse Aggregate | 4.54    | ≤3 or greater            |
| Fineness Modulus 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   | 29.09%  | ≤40% for wearing coarse  |
| Average Percentage Loss            |         |                          |
| Specific Gravity of Coarse Aggregate | 2.69    |                          |
| Apparent Specific Gravity of Coarse Aggregate | 2.7     |                          |
| Specific Gravity of Filler Stone Dust | 2.66    |                          |
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 hot mix asphalt pavement.

III. 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.

In Marshall Samples 3.5, 4, 4.5, 5, 5.5 and 6 percent bitumen was taken by weight of total sample weight was 1200 grams. However the only difference between conventional and nonconventional sample is that of filler material in such a way that in conventional samples stone dust was used as a filler material and in nonconventional samples stone dust was fully replaced by sugar cane bagasse ash (SCBA).

Table III: 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   | 15.35   | 39.03   | 9.43           | 2.47      | 2.32                     |
| 4              | 2.35 | 2.55 | 7.67   | 14.56   | 47.31   | 10.03          | 2.55      | 2.35                     |
| 4.5            | 2.38 | 2.48 | 3.74   | 13.82   | 72.88   | 9.32           | 2.83      | 2.38                     |
| 5              | 2.40 | 2.49 | 3.58   | 13.78   | 73.98   | 8.09           | 2.98      | 2.40                     |
| 5.5            | 2.44 | 2.51 | 3.17   | 12.83   | 75.26   | 7.87           | 3.10      | 2.44                     |
| 6              | 2.43 | 2.50 | 2.63   | 13.65   | 76.65   | 6.71           | 3.47      | 2.43                     |

Table IV: Marshal Result for Modified Marshall Samples (Bagasse Ash 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   | 43.74   | 7.13           | 2.09      | 2.34                     |
| 4              | 2.34 | 2.57 | 7.33   | 14.99   | 51.09   | 8.78           | 2.14      | 2.34                     |
| 4.5            | 2.37 | 2.55 | 5.78   | 14.44   | 59.97   | 8.29           | 3.63      | 2.37                     |
| 5              | 2.39 | 2.53 | 3.73   | 13.87   | 61.23   | 7.9            | 3.84      | 2.39                     |
| 5.5            | 2.43 | 2.59 | 2.92   | 13.99   | 68.48   | 6.27           | 4.02      | 2.43                     |
| 6              | 2.43 | 2.53 | 3.92   | 13.46   | 70.85   | 6.44           | 4.12      | 2.43                     |
From the above tables 3 and 4 and from their respective graphs the optimum binder content can easily calculate in such a way that OBC= (Air voids+ Unit weight+ Max Stability)/3.
The OBC values for the conventional and nonconventional samples were calculated by the above formula as 4.33 and 4.55 percent respectively.

IV. WHEEL TRACKING TEST

Wheel tracker test was conducted for finding out the rut resistance of HMA samples which were modified by using bagasse ash as a filler material.

Table V: Wheel Tracker Samples Description

| Test Temperature | SD Samples | BA Samples | Total Samples |
|------------------|------------|------------|---------------|
| 30 °C             | 3          | 3          | 6             |
| 60 °C             | 3          | 3          | 6             |

Table VI: Wheel Tracker Result Data For 30 °C

| No. of Passes | Rut Depth at 30 Degree of Stone Dust Filler Sample 1 | Rut Depth at 30 Degree of Stone Dust Filler Sample 2 | Rut Depth at 30 Degree of Stone Dust Filler Sample 3 | Rut Depth at 30 Degree of Bagasse Ash Filler Sample 1 | Rut Depth at 30 Degree of Bagasse Ash Filler Sample 2 | Rut Depth at 30 Degree of Bagasse Ash Filler Sample 3 |
|---------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| 0000          | 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                                              | 1.63                                              |
| 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                                              |

Figure 7: (a) Samples Prepared (B) Samples Cut by Cutter at Taxila

Figure 8: Comparison of Sample 1, 2 and 3 at 30 °C
The objectives of this research were to carry a comprehensive comparative study between upon the filler used in mix design. Marshall Samples were compared with each other having stone dust and bagasse ash was used separately as filler. Wheel tracking samples were prepared according to derived optimum bitumen content and these fillers were used and rut resistance was found out at different temperature conditions. This research work is discussed in detail in the previous chapters.

VI. PERFORMANCE BASED TESTING PROPERTIES

As natural filler stone dust achieved good Marshall Test results as compared to bagasse ash filler. Maximum stability of 10.04 KN and flow 3.47 mm were achieved by stone dust filler samples while maximum stability of 8.78 KN and flow of 4.12 mm were achieved by bagasse ash samples. From these results we concluded that maximum stability was given by stone dust filler samples were as maximum flow was given by bagasse ash samples.

VII. WHEEL TRACKING TEST DISCUSSION

Due to the greater demand for new highways constructions not only in Pakistan but all over the world the material demand and supply are creating issues. Therefore the researchers are in the effort to find some alternatives which will not only solve the material scarcity issue for HMA but also improve strength parameters. In the present research sugar cane bagasse ash which is agricultural waste was examined by using it as filler in HMA mix and its rut resistance was studied by wheel tracking machine for different temperatures. Wheel tracking samples were prepared according to the mix design and tested through the wheel tracking machine. Good resistance was shown at 30 OC by the samples having bagasse ash used as filler in mix design process. The rut occurred in bagasse ash samples was 1.97 mm whereas 2.31 mm rutting was recorded in stone dust samples. At 60 OC lesser rutting was recorded in stone dust samples which is 6.15 mm were as in bagasse ash samples 7.63 mm rutting occurred. (Note: these values are the average of three samples whose results are tabulated below).

VIII. CONCLUSION

Optimum binder content (OBC) increased up to 5 % (4.33 to 4.55) as compared to the OBC of conventional Marshall Sample. Maximum Marshall Stability of modified Marshall Samples reduced up to 12.47 percent as compared to maximum conventional Marshall Sample’s stability. Wheel tracking test modified samples has given the highest rutting resistance at temperature of 30 OC with an average rut depth of 14.47 percent lessor than conventional samples while at 60 OC conventional samples has given good lower rut resistance than modified samples of 19.39 percent.

Future Recommendations

The bagasse ash is construction friendly material without having harmful effects and available in abundance as byproduct of sugarcane with low initial cost. Further research can be carried out by using bagasse ash as a filler material in HMA with different target desirable properties such as resilient modulus, fatigue resistance, rutting resistance under submerged condition of water etc. Furthermore, the performance of bagasse ash is required to be checked as subgrade stabilizing materials under dry and soaked conditions.

Acknowledgment

I would like to thanks almighty Allah first and then all the co-authors for their full support and hard work we have completed this research study successfully.

Authors Contributions

The Idea and methodology to conduct this research work was proposed by Naveed Khan and Fazli Karim. The framework was prepared by Qaiser Iqbal. The technical implementation was done by Ayed Eid Alluqmani.

### Table VII: Wheel Tracker Result Data for 60 OC

| No of Passes | Rut Depth at 60 Degree of Stone Dust Filler Sample 1 | Rut Depth at 60 Degree of Stone Dust Filler Sample 2 | Rut Depth at 60 Degree of Bagasse Ash Filler Sample 1 | Rut Depth at 60 Degree of Bagasse Ash Filler Sample 2 | Rut Depth at 60 Degree of Bagasse Ash Filler Sample 3 |
|-------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| 0           | 0                                                 | 0                                                 | 0                                                 | 0                                                 | 0                                                 |
| 1000        | 2.21                                              | 1.17                                              | 2.22                                              | 2.55                                              | 2.55                                              |
| 2000        | 2.87                                              | 2.03                                              | 2.81                                              | 3.35                                              | 3.14                                              |
| 3000        | 3.46                                              | 2.37                                              | 3.43                                              | 3.82                                              | 3.69                                              |
| 4000        | 4.00                                              | 2.79                                              | 3.84                                              | 4.27                                              | 4.24                                              |
| 5000        | 4.4                                               | 3.11                                              | 4.31                                              | 4.77                                              | 4.75                                              |
| 6000        | 4.87                                              | 3.57                                              | 4.61                                              | 5.44                                              | 5.38                                              |
| 7000        | 5.44                                              | 3.9                                               | 5.08                                              | 5.98                                              | 5.87                                              |
| 8000        | 5.85                                              | 4.43                                              | 5.73                                              | 6.47                                              | 6.47                                              |
| 9000        | 5.97                                              | 4.69                                              | 6.35                                              | 6.81                                              | 6.76                                              |
| 10000       | 6.09                                              | 4.87                                              | 6.79                                              | 6.99                                              | 6.91                                              |
| 12000       | 6.2                                               | 5.02                                              | 6.91                                              | 7.06                                              | 7.03                                              |
| 14000       | 6.31                                              | 5.13                                              | 7.03                                              | 7.13                                              | 7.11                                              |

Figure 9: Comparison of sample 1, 2 and 3 at 60 OC
Conflict of Interest

The authors claims this work is original and not copied passed from other source either electronic or print media. The guidance taken from these sources are fully acknowledged and referenced as below.

Data Availability Statement

The testing data is available in this paper.

Funding

This research work is not funded by any agency/project.

References

[1] Perdomo, D., & Button, J. W. (1991). Identifying and correcting rut-susceptible asphalt mixtures.
[2] Anani, B. A., Balghunaim, F., & Swailmi, S. H. (1989). Effects of field control of filler contents and compaction on asphalt mix properties. Transportation Research Record, (1217).
[3] Chou, Y. J., & Lytton, R. L. (1991). Accuracy and consistency of backcalculated pavement layer moduli. Transportation Research Record, 1293, 72-85.
[4] Parker, F., & Brown, E. R. (1992). Effects of aggregate properties on flexible pavement rutting in Alabama. In Effects of aggregates and mineral fillers on asphalt mixture performance. ASTM International.
[5] Elliott, R. P., Ford Jr, M. C., Ghanim, M., & Tu, Y. F. (1991). Effect of aggregate gradation variation on asphalt concrete mix properties. Transportation Research Record, (1317).
[6] Vaitkus, A., Grazulyte, J., & Kleiziene, R. (2014). Influence of static and impact load on pavement performance. In Environmental Engineering. Proceedings of the International Conference on Environmental Engineering, ICEE (Vol. 9, p. 1). Vilnius Gediminas Technical University, Department of Construction Economics & Property.
[7] Xu, T., & Huang, X. (2012). Investigation into causes of in-place rutting in asphalt pavement. Construction and Building Materials, 28(1), 525-530.
[8] Aladjadjiyan, A. (Ed.). (2018). Agricultural Waste and Residues. BoD–Books on Demand.
[9] Harshwardhan, K., and Upadhyay K. (2017). "Effective utilization of agricultural waste: review.” J. Fundam. Renew. Energy. 237.
[10] Ormsby, W. C., & Fohs, D. G. (1990). Use of waste and by-products in highway construction. Transportation Research Record, 1288, 47-58.
[11] Hernández, J. M., Middendorf, B., Gehlke, M., & Budelmann, H. (1998). Use of wastes of the sugar industry as pozzolana in lime-pozzolana binders: study of the reaction. Cement and Concrete Research, 28(11), 1525-1536.
[12] Ali, K., Amin, N. U., & Shah, M. T. (2009). Physicochemical study of bagasse and bagasse ash from the sugar industries of NWFP, Pakistan and its recycling in cement manufacturing. Journal of the chemical society of Pakistan, 31(3), 375-378.