# Effect of Selected Conventional and Non-conventional Mineral Fillers with 'Enset' Fibers on Compaction Characteristics of Stone Mastic Asphalt Pavement (SMAP)

***Sinishat Belay [1)]*, Emer Tucay Quezon [2)] and Anteneh Geremew [3)]***

[1)] Civil Engineering Department, Jimma Institute of Technology, Jimma, Ethiopia.
* Corresponding Author. E-Mail: msinishat@gmail.com
[2)] Civil & Construction Engineering and Management Streams, Ambo Institute of Technology, Ambo, Ethiopia. E-Mail: emer.tucay@ambou.edu.et
[3)] Faculty of Civil & Environmental Engineering, Jimma Institute of Technology, Jimma, Ethiopia. E-Mail: anteneh.gerdi@ju.edu.et

## ABSTRACT

The content and type of ingredient materials are used to prepare the asphalt mix to affect the pavement surface's quality. This study aimed to investigate the compaction characteristics of Stone Mastic Asphalt Pavement (SMAP) mix using two different types of mineral fillers; namely, crushed stone and Ambo sandstone dust with local material enset fiber. Results indicated that the filler type and the content with or without fiber have a great effect on compaction characteristics of Stone Mastic Asphalt Pavement. The test results also showed that the addition of enset fiber in asphalt mix increases density, compaction energy and strength of asphalt mix and reduces Marshall flow of the mixes. Besides, crushed stone dust and Ambo sandstone dust with enset fiber affect the Marshall property and compaction characteristics of the stone mastic asphalt mix differentially. The Ambo sand stone dust filler has low density and has high binder absorption capacity compared with crushed stone dust filler in SMA mixes. In this study, the optimum binder content for the mixture by using Ambo sand stone dust (8%, 6.41%), (8.5%, 6.48%) & (10%, 6.43%) as well as the mixture using crushed stone dust filler at (8%, 5.84%), (8.5%,6.32%) & (10%,5.96%) was determined. The optimum fiber content obtained at 0.3% suggests that using enset fiber in stone mastic asphalt mixture improves the strength of asphalt pavements to resist external loads. The enset fiber at 0.3% better modifies stone mastic asphalt pavement properties. Finally, it is postulated that the performance of pavement is affected by filler type and content. Simultaneously, Marshall property has a linear relationship with compaction characteristics. It showed the possibility of constructing stone mastic asphalt pavement in Ethiopia by using locally available materials.

**KEYWORDS:** Enset fiber, Compaction characteristics, Marshall test, Pavement performance.

## INTRODUCTION

Good road infrastructure has long been considered one of the foremost indicators for measuring a nation's development. It is hence not surprising that most of the developed part of the world is notable for possessing the best road infrastructures when compared to the developing and underdeveloped world (Pojani and Stead, 2015) . Pavement engineering has existed as part of engineering discipline for a long time. However, its advancement in technology has not been boosted by discoveries in the methods of construction and construction materials compared to the other branches of engineering. The roads we see today do not differ much from those in the past years. However, recent advancements in construction equipment, construction materials, additives, testing equipment and last but not least, new design philosophies contribute to a new area of advancement in the road construction industry (Hainin, Reshi and Niroumand, 2010; M., Sh. and Ia, 2017; Kara De Maeijer, 2020).

Hot mix asphalt (HMA) is a paving material that

Received on 27/5/2020.
Accepted for Publication on 5/10/2020.

consists of asphalt binder, aggregate and mineral filler. The asphalt binder, which can be asphalt comer-modified asphalt cement, acts as a binding agent to glue aggregate particles into a cohesive mass. Because it is impervious to water, the asphalt binder also functions to waterproof the mixture. When bound by the asphalt binder, aggregate and mineral filler act as a stone framework to impart strength and toughness to the system. Because HMA contains both asphalt binder and mineral aggregate, the mixture's behavior is affected by the properties of the individual components and how they react with each other in the system (Zulkati, Diew and Delai, 2012; Mahan, 2013; Hafeez and Kamal, 2014; Ibrahim *et al.*, 2016; Hastuty, Sembiring and Nursyamsi, 2018; Mohammed and Fadhil, 2018; Chen and Solaimanian, 2019; Fan *et al.*, 2019; Khanghahi and Tortum, 2019; Mikhailenko, Ataeian and Baaj, 2020).

Stone matrix asphalt (SMA) is a gap-graded HMA developed in Germany in the 1960s to resist wear and tear on pavements caused by studded tires. Later, the mix was more rut-resistant and durable than conventional dense-graded mixtures, which encouraged other European countries to utilize this mixture. The SMA consists of 70-80% coarse aggregate, 12-17% fine aggregates, 8-13% fillers and 0.3% of fibers. Fibers used to minimize drainage of bitumen and to increase the stiffness of the mixture for compaction have quality control requirements and low production rate due to increasing mixing time (Kumar, Chandra and Bose, 2007; Hainin, Reshi and Niroumand, 2010; Panda, Suchismita and Giri, 2013; Choudhari and Malviya, 2018; Gummadi Chiranjeevi, 2018; Xavier *et al.*, 2018; Yuniarti, 2019).

The importance of proper compaction of asphalt pavements has been recognized for many years. Investigators have shown that pavement stability, durability, tensile strength, fatigue resistance, stiffness and flexibility are controlled to a certain degree by the density of asphalt concrete (Nega *et al.*, 2013; Gao, Huang and Yu, 2014; Kassem *et al.*, 2015; Enwuso A. Igwe, Emmanuel O. Ekwulo and Captain G. Ottos, 2016; Salem *et al.*, 2017; Nare and Hlangothi, 2019).

In this study, Marshall stability and compaction tests are conducted to investigate SMA mixes' compaction characteristics by using two types of mineral fillers; namely, crushed stone dust and Ambo sandstone dust with local material enset fiber, in the laboratory.

## EXPERIMENTAL INVESTIGATION

### *Research Design*

This research is designed based on an experimental study on the properties of different ingredient materials of SMA pavement after reviewing different literature, journals, standards, specifications and manuals. A laboratory test was performed at different stages to accomplish the specific objectives of this research.

First, material quality test for raw materials, like aggregate, bitumen, filler (crushed stone dust & Ambo sandstone dust) and fiber (enset fiber) was conducted.

Second, sieve analysis was carried out for the SMA mixtures to obtain the grading sizes followed by aggregate blending to obtain the binder course gradation curve used to prepare the asphalt mix based on NCHRP specifications.

Third, the asphalt mix samples were prepared based on the Marshall test method requirements at different bitumen contents (5%, 5.5%, 6% and 6.5%) and different filler contents (8%, 8.5% and 10%) to determine optimum bitumen content and optimum filler and to select the optimum fiber content based on good Marshall stability value of the asphalt mix step by step for two types of filler at three fiber contents.

Marshall mix design test was conducted for SMA mix by using two types of filler (crushed stone dust and Ambo sandstone dust) individually at different compaction blows (35, 50 and 75) to determine the effect of these two types of filler on Marshall properties and compaction of the mix. After that, Marshall test was utilized to evaluate these mixes' Marshall properties and compaction characteristics. Finally, laboratory test results are analyzed. Conclusions and recommendations were drawn based on the test results found.

## MATERIALS

The materials used in this study are locally available materials found from the surroundings of Jimma and Ambo town. Crushed stone dust filler and aggregate were obtained from Ethiopian road authority Jimma district quarry and crusher site located at Denba, Ambo sandstone filler from a natural source located at Ambo-Senkelle quarry site (120 km from Addis Ababa), which is full of dust film on its surface. For this reason, Ambo sandstone dust was washed thoroughly to remove silt and clay, dried and crushed before undergoing any test. Enset fiber was purchased from the local market of Jimma town and bitumen with the penetration grade of 60/70 was also obtained from Ethiopian road authority Jimma district. 60/70 penetration grade bitumen was selected for this study due to the fact of its better quality as compared with 85/100 penetration grade bitumen.

## RESULTS AND DISCUSSION

**Table 1. Physical properties of enset fiber**

| Average moisture loss % | Average diameter (mm) | Average strength (MPa) |
|---|---|---|
| 0.606 | 0.017 | 23.8 |

### *Physical Properties of Mineral Fillers*

Two types of fillers are used for this study; conventional mineral filler crushed stone dust and non-conventional mineral filler Ambo sandstone dust. To evaluate the physical properties of each mineral filler, a number of laboratory tests were conducted, like sieve analysis, specific gravity and plastic index tests. The specific gravity tests were conducted based on ASTM D-854 by using a distilled water pycnometer method.

**Table 2. Physical properties of mineral fillers**

| Physical properties | Filler type | | Method of test |
|---|---|---|---|
| | Crushed stone | Ambo sandstone | |
| % passing 0.075 mm sieve | 100 | 100 | ASTM 117 |
| Specific gravity | 2.82 | 2.76 | AASHTO T85-100 |
| Plasticity index | NP | NP | AASTO T89-90 |

### *Effect of Filler Type and Content on the Marshall Stability of SMA*

Both fillers show the same trend on Marshall stability. As filler content increases, stability also increases up to maximum. When the filler content is low, the mixes' air void becomes high and the filler may be insufficient to fill the air void. When the filler content is too high, the mix becomes too stiff, which leads the mix to break and become difficult to compact due to segregation of material. Hence, both cases affect the stability of asphalt mixtures. Therefore, the stability value increases with filler content only up to its maximum. Then, the filler content becomes too high and the mixes become fractured or fail.

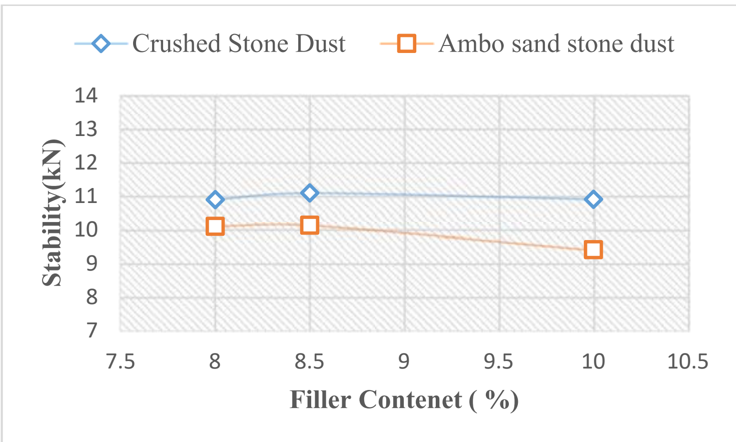


**Figure (1): Effect of filler type and content on Marshall stability at OBC**

***Effect of Filler Type and Content on the Void in the Mineral Aggregate (VMA)***

It is expected that when the filler content in asphalt mixture increases, the void decreases significantly. This is due to the mineral filler particle size in the mixture. On the other hand, if the filler type used is coarser, the air void increases, which produces a low bond between the particles. During the process of compaction, the coarser particles are converted into the filler size, which increases the filler content, resulting in a decrease of air void in the hot mix asphalt.


**Figure (2): Effect of filler type and content on VMA at OBC**

***Effect of Filler Type and Content on the Void Filled with Asphalt (VFA)***

The Marshall criterion for VFA is more related to the durability of asphalt mixtures. If the void filled with asphalt binder is lower than the specification criteria, the amount of asphalt binder to coat the aggregate particles becomes lower. This leads to an increase in the air void in the mixture. Its effect is related to the compaction problem by separating ingredient material particles, subsequently reducing the durability of asphalt pavement. On the other hand, if the VFA is above the specification limit, due to the excess amount of asphalt binder in the mixes, more voids are filled with asphalt and the whole surface of aggregate particles is covered with asphalt and filler particles float over the asphalt binder. This reduces the durability of asphalt mixtures by decreasing stiffness and increasing the pumping of the binder. As shown in Fig. 3 for the variety prepared by both types at all contents, the void filled with asphalt binder obtained is within the limit of Marshall specification criteria (65%-75%). As filler content increases up to its optimal limit, the VFA also increases. If it is above its optimum value, it reduces the duality and performance of asphalt pavement.

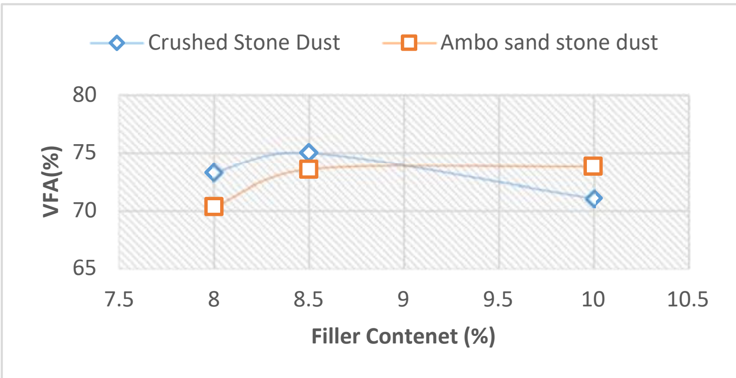


**Figure (3): Effect of filler type and content on VFA at OBC**

***Effect of Filler Type and Content on Marshall Flow***

Marshall flow value is more related to binder content, as binder content in the mixes increases the flow value. As the binder content decreases, the flow also decreases. It is indirectly related to filler type and content; as the amount of filler absorbed increases, the amount of binder in the mixes increases. The absorption capacity of different filler types is varied. Some filler with a small amount absorbs an excess amount of binder. Other types with a large amount absorb a small amount of binder. In some fillers, as the filler content increases, the binder's absorption by the filler directly increases and the reverse is true.

In this study, two filler types were used; namely, crushed stone and Ambo sandstone dust (8%, 8.5% and 10%). The filler content at 8% of both showed a high flow value than other contents (4% & 3.894%), respectively. Lower flow value of 3.476% was obtained at 8.5% of crushed stone dust filler. This can be obtained from the relationship as demonstrated in Figure 4.

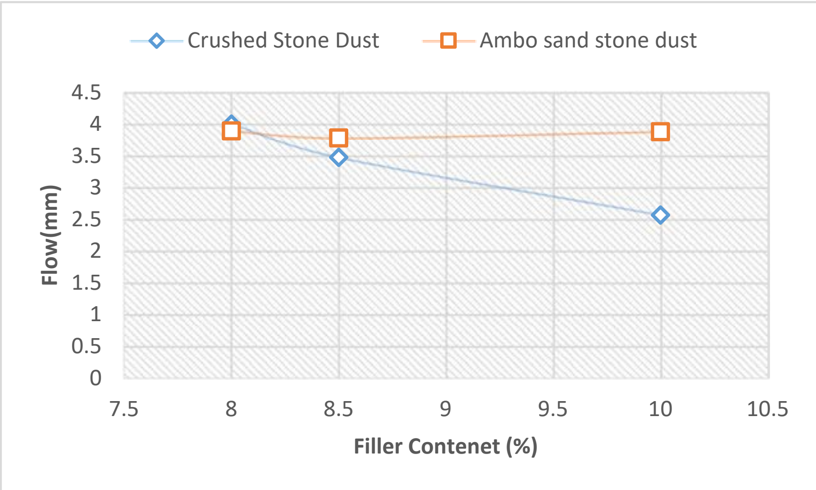


**Figure (4): Effect of filler type and content on Marshall flow at OBC**

***Effect of Filler Type and Content on the VA of SMA Mixes***

In asphalt mixtures, the void filled with air, asphalt and filler performed to attain the design density. However, when the whole void space is filled with filler, the mix becomes too stiff. When the filler content increases, the air void decreases up to optimum value of filler content. Beyond the optimum value, the filler content increases and the air void also increases. From this result, the mixes start to fail during the compaction process, indirectly affecting the performance of asphalt pavement.

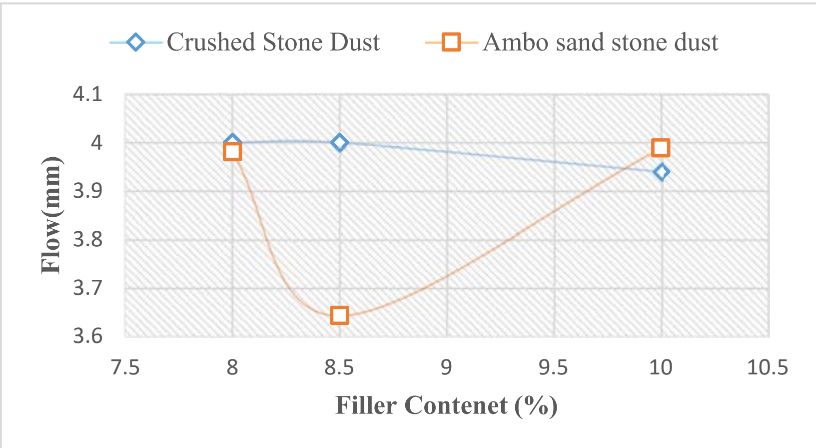


**Figure (5): Effect of filler type and content on VA at OBC**

***Effect of Fiber on Marshall Properties of SMA Mixtures***

The laboratory test on the optimum bitumen content (OBC) and optimum filler content (OFC) with different fiber contents indicated an essential effect on Marshall properties and compaction characteristics of hot mix asphalt. OBC and OFC were determined without fiber for the two types of filler to examine the effect of fiber addition by controlling the filler and binder contents to the optimum. Table 3 shows the test results of asphalt mixes at 0 %, 0.3% and 0.5% fiber addition of SMA mixtures.

**Table 3. Marshall properties of SMA mixes at OBC, OFC and different fiber contents**

| Marshall property | Filler type | Fiber content (%) | | |
|---|---|---|---|---|
| | | 0 | 0.3 | 0.5 |
| VA (%) | Crushed stone dust | 4.0 | 3.40 | 4.1 |
| | Ambo sand stone dust | 3.643 | 3.31 | 3.99 |
| VMA (%) | Crushed stone dust | 15.359 | 15.29 | 19.35 |
| | Ambo sand stone dust | 14.064 | 16.072 | 17.73 |
| VFA (%) | Crushed stone dust | 74.989 | 72.49 | 66.821 |
| | Ambo sand stone dust | 73.559 | 69.229 | 70.612 |
| Stability(KN | Crushed stone dust | 11.09 | 13.74 | 10.91 |
| | Ambo sand stone dust | 10.134 | 11.92 | 9.98 |
| Flow(mm) | Crushed stone dust | 3.476 | 3.14 | 3.05 |
| | Ambo sand stone dust | 3.781 | 3.281 | 3.19 |

Table 3 illustrates the effect of fiber content on Marshall properties, which also affects SMA mixes' compaction characteristics. The results indicated that if the mixture's fiber content increases, stability also increases up to its optimum value. The fiber in asphalt mixes is used to minimize the draining of asphalt binder through the void and make the mix stiff enough to attain the design density by compaction. On the other hand, when the fiber content is above its optimum value, the hot mix asphalt becomes too stiff, because the fiber absorbs the excessive amount of the binder. When the binder content in the mixes decreases, the material particles become easily segregated, and finally, during compaction at lower energy, the mixes fail. This will cause a reduction in the stability value and affect other Marshall properties of asphalt mixtures. Table 3 shows such effect of fiber content in this study. The stability value increases at 0.3% and decreases at 0.5% of enset fiber.

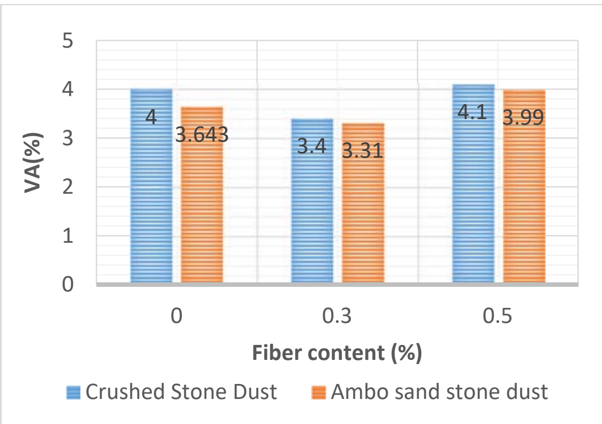


**Figure (6): Effect of fiber content on VA (%)**

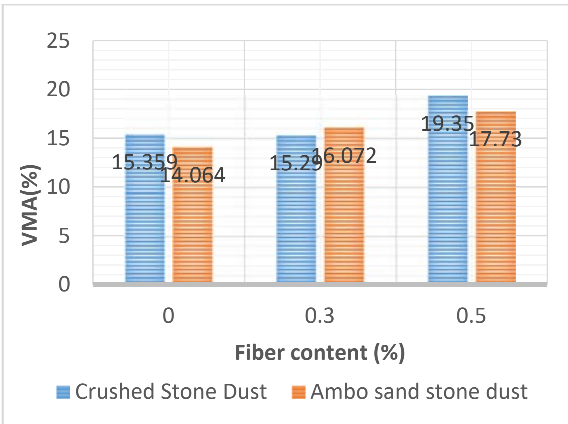


**Figure (7): Effect of fiber content on VMA (%)**

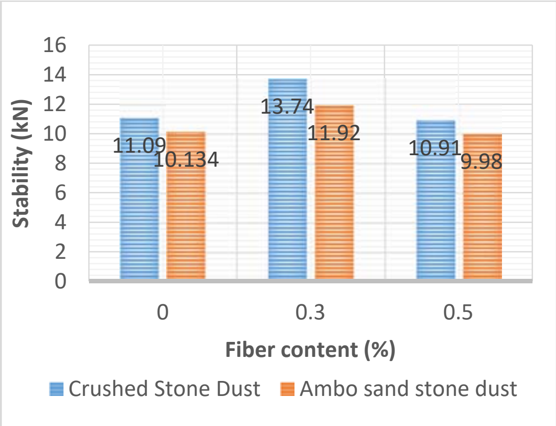


**Figure (8): Effect of fiber content on stability (kN)**

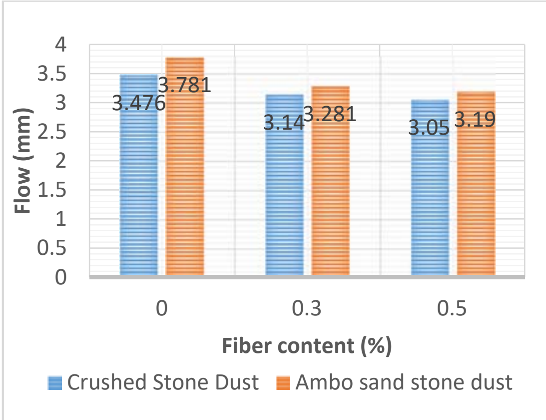


**Figure (9): Effect of fiber content on flow (mm)**

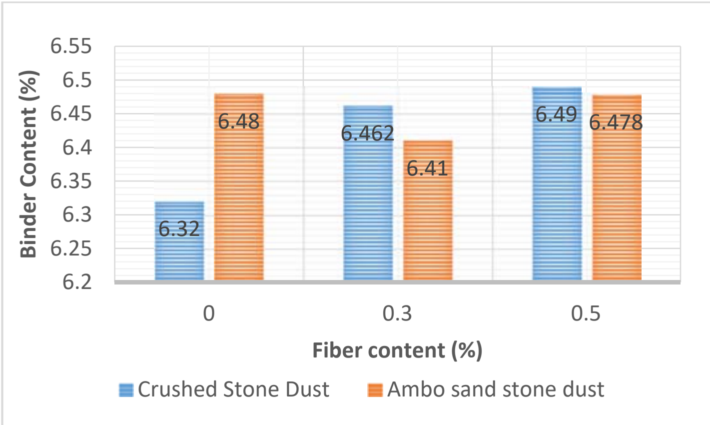


**Figure (10): Effect of fiber content on binder content (%)**

The above figures demonstrate a comparison of the effect of enset fiber content on Marshall properties and determine the optimum fiber content of enset fiber. Cellulose fibers absorb maximum amount of bitumen during mixing; this increases the asphalt mixture's stiffness. As a result of the experimental study, 0.3% enset fiber samples gave higher stability than the other mixtures. At 0.5% enset fiber, the stability value decreased. The stability values up to 0.3% of enset fiber increased and then reduced at 0.5%. Optimum bitumen content and optimum filler content are selected to demonstrate the effect of fiber addition on Marshall properties of SMA mixes.

Figures 6, 7, 8, 9 and 10 show a comparison of all the mixtures; it was found that 0.3% of enset fiber samples indicated higher stability than all other mixtures. So, 0.3% enset fiber is considered optimal according to maximum Marshall stability. From here, 0.3% enset fiber has been selected as an additional stabilizing material for further study by considering its stability, OBC, VA and flow that satisfactorily met all of the established criteria. Hence, the analysis for the effect of filler type with enset fiber on compaction characteristics of SMA mixtures was performed for OBC, OFC and OFRC (6.462% for CSD and 6.41% for ASSD), (8.5% for both filler types) and (0.3% enset fiber for both types of filler), respectively, as used in the study.

**Correlation of Marshall Properties with Compaction Characteristics of Stone Mastic Asphalt Pavement**

This study was conducted to investigate the effect of selected conventional and non-conventional mineral fillers with enset fiber on SMA mixtures' compaction characteristics and correlate Marshall properties with compaction characteristics under different compaction blows (35, 50 &75) on both types. The compaction characteristics of asphalt mixture are determined by gradation, temperature and viscosity of bituminous material and number of blows (Gao, Huang and Yu, 2014).

The best trend for bulk density with different compaction blows plot is a linear correlation with a high degree of determination ($R^2$=0.9906), as illustrated in Figure 11 with the corresponding equation:

$$\text{Bulk density (g/cm}^2\text{)} = 0.0021NB + 2.2869$$

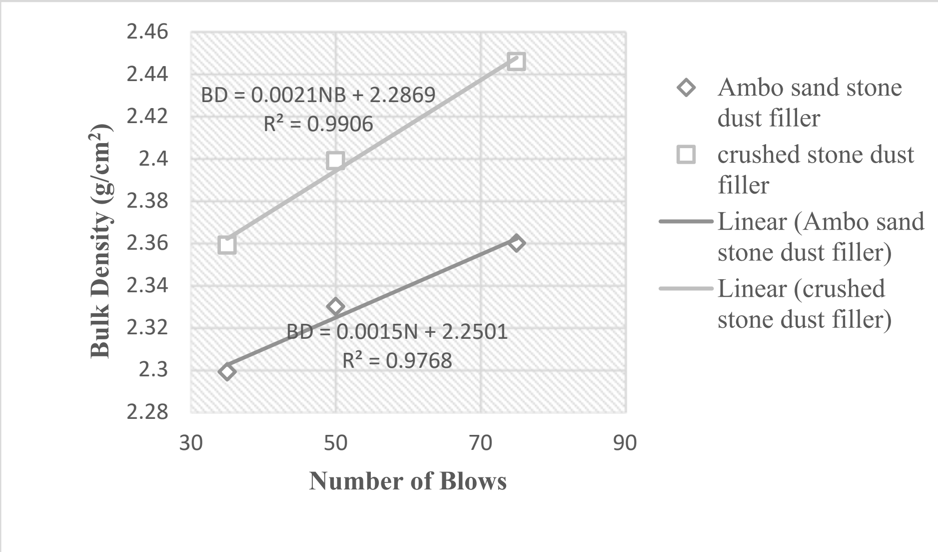


**Figure (11): Effect of compaction on bulk density with two filler types**

The linear trend line for VA (%) *versus* several blows gave a high degree of determination ($R^2$=0.96), as shown in Figure 12 and the corresponding linear equation: VA(%)=-0.041NB+6.7255

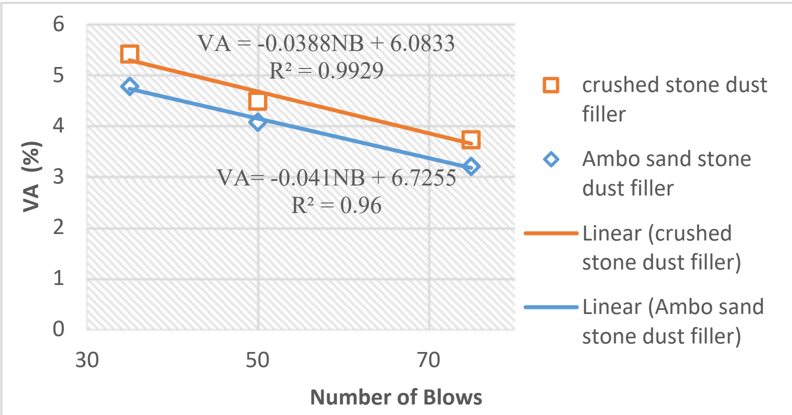


**Figure (12): Effect of compaction on air void with two filler types**

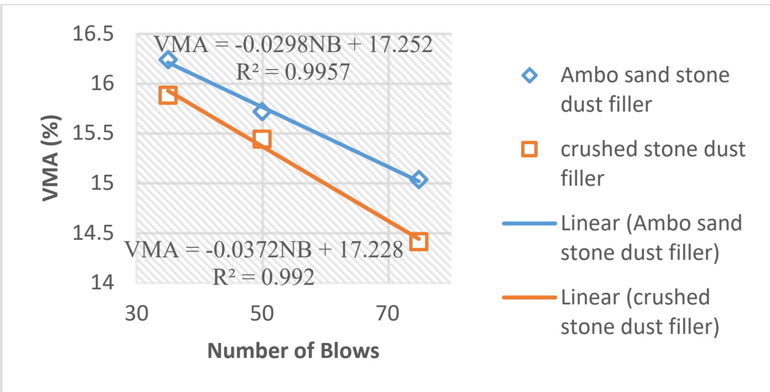


**Figure (13): Effect of compaction on mineral aggregate with two filler types**

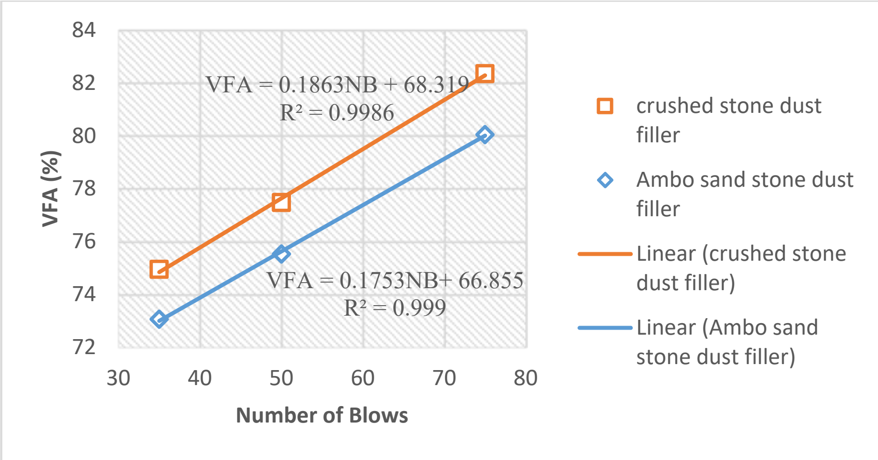


**Figure (14): Effect of compaction on void filled with asphalt using two filler types**

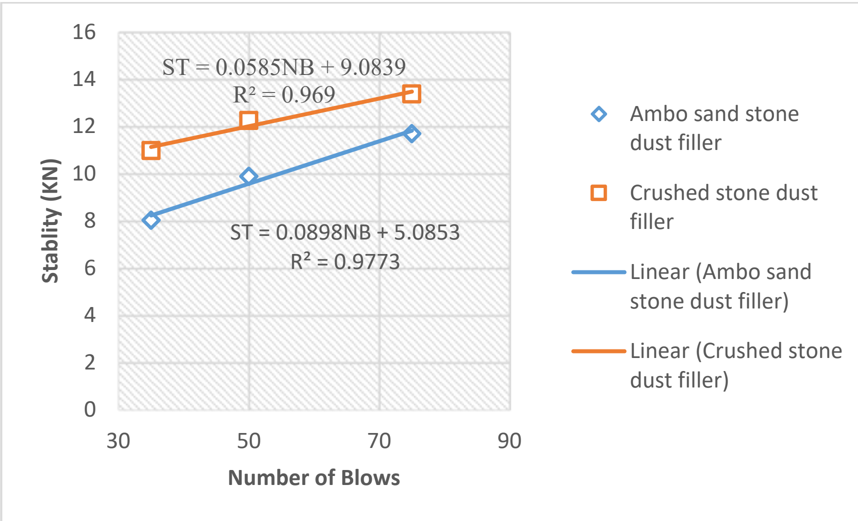


**Figure (15): Effect of compaction on air void for two filler types**

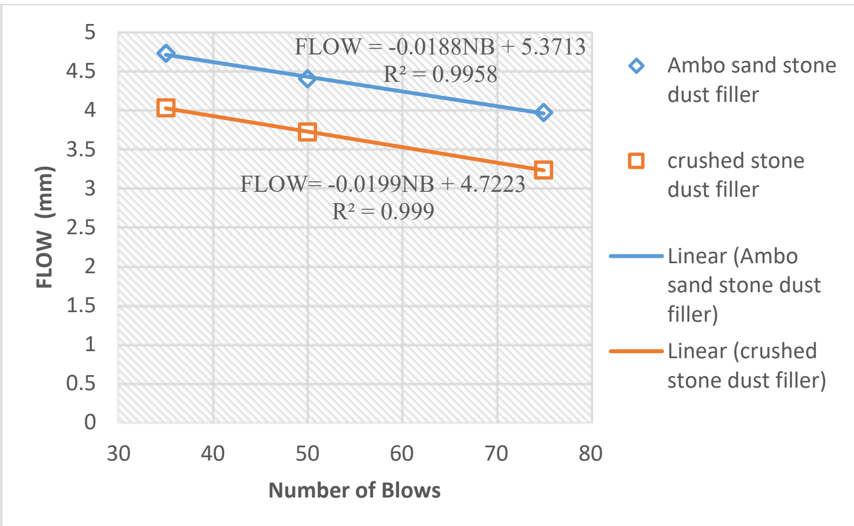


**Figure (16): Effect of compaction on flow for two filler types**

The previous figures illustrated that Marshall properties are directly related to SMA mixtures' compaction characteristics for both types of filler. The linear regression model was developed and Marshall properties correlate with compaction characteristics using different compaction blows. The bulk density indicated a strong relationship with compaction energy at 35, 50 and 75 blows by $R^2$ values of 0.9906 for CSD and 0.9768 for ASSD. The graphs also showed a linear relationhip at a confidence level of 95%. The significance factor at mix with CSD of bulk density was 0.06170594, at a combination with ASSD of 0.13385760.

## CONCLUSION

Crushed stone dust filler has different properties compared to Ambo sand stone dust filler. The selected conventional and non-conventional mineral fillers affect the Marshall properties and compaction characteristics of stone mastic asphalt mix in different ways. The traditional filler of mineral CSD with enset fiber at OBC, OFC & OFBR (6.32%, 8.5 % & 0.3%) content, respectively, has a high bulk density, high air void, low void in mineral aggregate, high stability and lower flow than the non-conventional Ambo sand stone dust filler with enset fiber at OBC, OFC & OFBR (6.48%, 8.5% and 0.3%) content, respectively, at 35, 50 and 75 blows.

Enset fiber used in stone mastic asphalt mixes as a stabilizing additive at its optimum content shows modification on the properties of asphalt mixes by decreasing air void and flow. It also increases the stability of SMAP at all compaction blows used in this experimental work. A linear regression model was developed by correlating Marshall properties, such as bulk density (%), VA (%), VMA (%), degree of compaction (%), stability (kN) and flow (mm), with compaction characteristics at different blows of 35, 50 and 75 by using each filler type with enset fiber at optimum content. From these results, it is concluded that Marshall properties are directly related to Stone Mastic Asphalt Pavement (SMAP) characteristics.

**Funding**

The authors received no direct funding for this research.

**Acknowledgment**

The authors would like to express their gratitude to Jimma Institute of Technology for support to finish this research work.

## REFERENCES

Chen, X., and Solaimanian, M. (2019). "Evaluating fracture properties of crumb rubber-modified asphalt mixes". International Journal of Pavement Research and Technology, 12 (4), 407-415; doi: 10.1007/s42947-019-0048-6.

Choudhari, C., and Malviya, P. (2018). "A review paper study on stone matrix asphalt using banana fibre".

Enwuso A. Igwe, Emmanuel O. Ekwulo, and Captain G. Ottos. (2016). "Moisture effect on stiffness of asphalt concretes for low-volume roads: Comparative study of Asphalt Institute and Witczak 1-40D models". International Journal of Constructive Research in Civil Engineering, 2 (4), 12-19; doi: 10.20431/2454-8693.0204002.

Fan, Z. et al. (2019). "Effects of cement–mineral filler on asphalt mixture performance under different aging procedures". Applied Sciences, 9 (18), 3785; doi: 10.3390/app9183785.

Gao, Y., Huang, X., and Yu, W. (2014). "The compaction characteristics of hot mixed asphalt mixtures". Journal of Wuhan University of Technology-Mater. Sci. Ed., 29 (5), 956-959; doi: 10.1007/s11595-014-1027-z.

Gummadi Chiranjeevi. (2018). "Analysis of stone matrix asphalt (SMA) with interactive properties of gradation". International Journal for Modern Trends in Science and Technology, 4 (4), 83-87.

Hafeez, I., and Kamal, M.A. (2014). "An experiment-based approach to predict asphalt mixture permanent deformation behavior". Arabian Journal for Science and Engineering, 39 (12), 8681-8690; doi: 10.1007/s13369-014-1453-4.

Hainin, R., Reshi, W.F., and Niroumand, H. (2010). "The importance of stone mastic asphalt in construction".

Hastuty, I.P., and Sembiringand Nursyamsi, I.S. (2018). "Comparison of compressive strength of paving block with a mixture of Sinabung ash and paving block with a mixture of lime". IOP Conference Series: Materials Science and Engineering, 309, 012011; doi: 10.1088/1757-899X/309/1/012011.

Ibrahim, A.N.H. et al. (2016). "Performance evaluation of stone mastic asphalt (SMA) using geopolymer as an asphalt modifier". Jordan Journal of Civil Engineering, 10 (4), 9.

Kara De Maeijer, P. (2020). "Special issue: Recent advances and future trends in pavement engineering". Infrastructures, 5 (4), 34; doi: 10.3390/infrastructures 5040034.

Kassem, E. et al. (2015). "Development of compaction monitoring system for asphalt pavements". Construction and Building Materials, 96, 334-345; doi: 10.1016/j.conbuildmat.2015.07.041.

Khanghahi, S.H., and Tortum, A. (2019). "Examination of the possibility of using gilsonite in hot mix asphalt concrete". Jordan Journal of Civil Engineering, 13 (1), 13.

Kumar, P., Chandra, S., and Bose, S. (2007). "Laboratory investigations on SMA mixes with different additives". International Journal of Pavement Engineering, 8 (1), 11-18; doi: 10.1080/10298430600987381.

M., R., Sh, B., and Ia, B. (2017). "Road construction, maintenance challenges and their solutions in Kashmir". Irrigation & Drainage Systems Engineering, 06 (01); doi: 10.4172/2168-9768.1000182.

Mahan, H.M. (2013). "Influence of mineral filler- asphalt ratio on asphalt mixture performance". Engineering Sciences, 10.

Mikhailenko, P., Ataeian, P., and Baaj, H. (2020). "Extraction and recovery of asphalt binder: A literature review". International Journal of Pavement Research and Technology, 13 (1), 20-31; doi: 10.1007/s42947-019-0081-5.

Mohammed, A.M., and Fadhil, A. T. (2018). "Effect of filler type on the durability of asphalt concrete mixes". International Journal of Current Engineering and Technology, 8 (3); doi: 10.14741/ijcet/v.8.3.36.

Nare, K., and Hlangothi, S.P. (2019). "Optimizing co-blends of crumb rubber and ethylene vinyl acetate in 70/100 bitumen". Jordan Journal of Civil Engineering, 13 (4), 12.

Nega, A. et al. (2013). "Pavement materials' characterization of hot-mix asphalt mixes in western Australia". Advanced Materials Research, 723, 434-443; doi: 10.4028/www.scientific.net/AMR.723.434.

Panda, M., Suchismita, A., and Giri, J. (2013). "Utilization of ripe coconut fiber in stone matrix asphalt mixes". International Journal of Transportation Science and Technology, 2 (4), 289-302; doi: 10.1260/2046-0430.2.4.289.

Pojani, D., and Stead, D. (2015). "Sustainable urban transport in the developing world: Beyond megacities". Sustainability, 7 (6), 7784-7805. doi: 10.3390/su 7067784.

Salem, Z.T.A. et al. (2017). "Effect of waste glass on properties of asphalt concrete mixtures". Jordan Journal of Civil Engineering, 11 (1), 15.

Xavier, R.M. et al. (2018). "A review on fiber-modified stone matrix asphalt". 05 (03), 3.

Yuniarti, R. (2019). "Resistance to degradation of porous asphalt mixture using pine resin as asphalt modifier". Jordan Journal of Civil Engineering, 13 (1), 11.

Zulkati, A., Diew, W.Y., and Delai, D.S. (2012). "Effects of fillers on properties of asphalt-concrete mixture". Journal of Transportation Engineering, 138 (7), 902-910; doi: 10.1061/(ASCE)TE.1943-5436.0000395.