Influence of Natural Fibers as Additive on Characteristics of Stone Mastic Asphalt

Pragnya Parimita
Department of Civil Engineering, Silicon Institute of Technology, Sambalpur, Odisha, India
E-mail: payalpragnya@gmail.com

Abstract. The purpose of this article is to emphasize on the development of stabilized Stone Mastic Asphalt Mix for laudable and tangible pavement performance. Attempts have been made to stabilize SMA Mix using synthetic fibers which is too costly and not readily available. The concept of using natural fibers and waste materials to replace these energy intensive synthetic fibers or polymer additives is a recent development in this field. India, being an agricultural economy, produces fairly huge quantity of natural fibers such as coconut, sisal, banana, sugar cane, jute etc. The addition of these natural fibers as additives to SMA has really thrust a revolutionary change to the transport system. This research is an attempt to propose an ideal surface course for the pavement of India using natural fibers stabilized SMA that can face rough weather conditions and more loads. Analyzing the illustrated results of the comparative study on the performance of the stabilized mixtures it is inferred that additive plays a prominent role in the volumetric, mechanical and drain down characteristics of SMA. Improved Marshall Quotient and Marshall Stability value show higher rutting resistance and improved tensile strength shows better Cracking Resistance. This study brings out the importance of additives in SMA and proposes an eco-friendly alternative to Synthetic fibers.

1. Introduction
The development of economic scenario of a nation relies on the strength of transportation, hence strength of roads gains paramount importance. The ruts and its repeated mending weaken the infrastructure of national economy. In spite of multifarious steps to strengthen pavements, ruts continue, so also national loss and this gives birth to innovative thoughts to check this decay. SMA is one of the acceptable and successful options for the durability and load bearing capacity, for its rut resistance and water resistance. It flourished in Germany during 1960s but it gained acceptance in all countries for its effectiveness. SMA Mix faces drain down problem for laxity of binder and matrix; hence, innovative efforts continue to check the drain down by the use of additives as stabilizing agents. The addition of fibres in the required proportion works as better interlock between aggregates. The flexible pavement committee has announced the authenticity of SMA in Indian conditions, but it is realized that the imported fiber used as stabilizer to the aggregates leads to an additional cost of construction. For sometimes, it was thought of using waste tyres, carpet, waste plastic bags and bottles...
as stabilizing agent but its processing cost appeared to be high, economic burden in acquisition of fiber continues. Therefore it is necessary to think of a fibre that can be obtained in plenty but at low cost. [7-12].

In the context of our country, it is marked that natural fibres like jute, sisal, banana and coconut are accumulated from varied sources. It is rightly felt that the cost of construction can be minimized by the application of such fibres. However, out of these, banana and coconut fibres are of better choice for their plenty production in one hand and easy collection from the waste in the other. The huge production of coconut in the coastal area and the large-scale banana plantation in all parts of our country show an easy way of collecting fibres from the waste i.e. from coconut coir and banana stem [4-7].

2. Materials

Proper material, suitable mixing and right proportion play prominent role in the SMA. Properly graded aggregates of good quality sized between 0.075mm and 19mm mixed with sufficient bitumen provide an elastic quality. The right proportion of bitumen, coarse aggregates, fillers and fine aggregates makes the bituminous mix strong.

The function of bituminous surfacing is largely determined by the quality and proportion of materials. SMA mixtures are prepared by using aggregates of good quality, bituminous binder, stabilizer and mineral fillers. In SMA stone contact is important as it creates a gap graded skeleton like stone structure. The voids of the structural matrix are filled by high viscosity bituminous mastic. 70% stone on stone contact is ensured after compaction of the mix. Mastic stiffness of the required proportion is obtained for the use of crushed sand in the mix. Along with indigenous materials of western Odisha such as aggregates, bituminous binder, banana fibres and coir are used as additives to attain stabilization.

2.1. Aggregates

The strength and stiffness of SMA along with rut resistance largely depend on the size and quality of aggregates. The ministry of road transport and highways (MORTH) [9], National Cooperative Highway Research Project (NCHRP) and National Asphalt Pavement Association (NAPA) have determined the nominal maximum aggregate size (NMAS) to be 19mm, 13mm and 10 mm respectively for the better results of SMA mixture. For the purpose of study, coarse aggregates of 13mm nominal size have been used. In Table 1, the gradation of the aggregates required as per specification in MORTH for stone mastic asphalt has been reflected. Qualities of the aggregates were checked by performing various tests as per IRC: SP: 79 - 2008 specifications shown in Table 2.

Table 1. Aggregates Gradation Used

| Size of sieve (mm) | Cumulative percentage passing | Gradation Used | percentage retained | Weight per sample (gm) |
|------------------|--------------------------------|----------------|---------------------|------------------------|
| 19               | 100                            | 100            | 0                   | 0                      |
| 13.2             | 90-100                         | 95             | 5                   | 60                     |
| 9.5              | 50-75                          | 65             | 30                  | 360                    |
| 4.75             | 20-28                          | 25             | 40                  | 480                    |
| 2.36             | 16-24                          | 20             | 5                   | 60                     |
| 1.18             | 13-21                          | 17             | 3                   | 36                     |
| 0.6              | 12-18                          | 15             | 3                   | 36                     |
| 0.3              | 10-20                          | 14             | 1                   | 12                     |
| 0.075            | 8-12                           | 10             | 4                   | 48                     |
| <0.075           | --                             | --             | 9                   | 108                    |
Table 2. Physical Characteristics of Aggregates used

| Property                        | Test Results | Standard Range |
|---------------------------------|--------------|----------------|
| Impact value (%)                | 13.22%       | 27% maximum    |
| Crushing Value (%)              | 17.65%       | 30% maximum    |
| Los Angeles Abrasion Value (%)  | 16.24%       | 35% maximum    |
| Water Absorption (%)            | 0.8%         | 1.3% maximum   |
| Combined elongation and flakiness index (%) | 32.29%        | 35% maximum    |
| Specific Gravity                | 2.67         | 3 maximum      |

2.2. Bitumen

Bitumen has its special place and role in the SMA Mix as it binds polymers, aggregates, fillers and additives. A slightly higher amount of bitumen is used as compared to conventional mixes for better performance. As bitumen is viscoelastic in nature climatic condition, time of loading and maximum temperature of that locality ascertain the grade of bitumen used for construction and keeping this in view VG30 grade of bitumen has been used for the SMA samples.

Table 3. Physical Characteristics of bitumen used

| Properties                        | Test Results | Standard Range |
|-----------------------------------|--------------|----------------|
| Penetration value (1/10th of mm)  | 65.2         | 50-70          |
| Ductility value (cm)              | 89.8         | Minimum 40     |
| Softening Point (°C)              | 51.5         | Minimum 47     |
| Specific gravity                  | 1.01         | 0.97-1.02      |

2.3. Filler

In SMA Mix, fillers are used to improve the strength and quality of the mixture. Rock dust, slag dust, hydraulic cement, fly ash and hydraulic lime are added as fillers. Besides providing stiffness to the mix, the fillers help to check rutting. Further, the longevity of the mix is increased as fillers lower the drain down of binders. For admirable performance proportion of filler material passing through 0.075mm sieve should be greater than 95%. Increasing filler amount more than required limit leads to crack formation in the mix. On the other hand if filler amount is reduced it decreases the resistance against rutting. In the preparation of samples, the fillers having specific gravity of 2.87 have been used.

2.4. Fibers

For confirmation of stability in the SMA Mix, addition of fibre as an additive is essential. Fibres collected from manmade materials like waste tyre and carpet are found less efficacious, less eco-friendly than that of fibres collected from natural sources. Collection of natural fibres is also less expensive as it is obtained from the waste. Cellulose fibres are directly collected from jute, cotton, flex and ramie, but manmade fibres are collected and used as consumer or industrial products like rayon and acetate etc. Natural fibres collected from banana stem and waste part of ripe coconut have been used for study purpose for their strong intermolecular forces, high linearity of cellulose molecules that attach crystalline nature to fibres collected from rich natural sources. Coconut fiber is more effective in the SMA Mix for its easy availability, higher cellulose and lignin content that provide extra water resistance as well as stability. Coir fiber with specific gravity value of 1.47 has been used for sample preparation.

Banana fiber as an additive in the SMA Mix has its own merit for its profusion, high tensile strength, and high resistance to wear and tear. Its specific gravity is 1.33 which is used for sample preparation.
2.5. Optimum Bitumen Content

It is marked that without fibre the optimum bitumen content for SMA is 6.36%, almost 5.95% of the total mix by weight. But after adding 0.3% of coconut fibre the optimum bitumen content goes up to 6.46% which is 6.06% by weight of the total mix. But in case of banana fibre the estimate becomes different. With adding of 0.3% of banana fibre the optimum bitumen content of the mix becomes 6.36% which is 6.03% by weight of the total mix. All these values have been obtained by calculating the average value of bitumen content corresponding to 4% air voids, maximum density and maximum stability.

3. Experimental Procedure

3.1. Marshall Test

Marshall Stability Test was conducted as per ASTM D 6927 - 06 specifications and procedure. For the measurement of plastic deformation resistance of the cylindrical specimen after compaction, loading rate of 51 mm per minute has been applied to a specimen along its diameter. In the Marshall Method Density-void analysis and Stability-flow tests are two major features. Marshall Stability value is the maximum load sustained at a standard test temperature of 60°C by the test specimen. In terms of one fourth of mm unit, the deformation of specimen is evaluated due to maximum loading which is termed as flow value. This test helps to know the optimum bitumen content required for the gradation of aggregates used and desired traffic.

3.2. Test Specimen preparation

- To achieve specified gradation for SMA as per MORTH required amount of aggregates of different sizes were accumulated and mixed.
- With weight of 1200 gm. 3 samples of SMA were made ready for different cases by increasing the bitumen content by 0.5% from 5 to 7% with and without fibre.
- To achieve sufficient fluidity for mixing both aggregates and bitumen were heated with proper observation so as to avoid overheating.
- All materials were mixed at stipulated temperature to get homogeneous SMA Mix.
- Using a standard hammer 50 blows were applied to the prepared mix so placed on specified mould.
- After removing the samples from the mould and bringing the mix to surrounding temperature, the samples were analyzed.

Parameters calculated were Specific Gravity of the mix ($G_t$), Bulk specific gravity ($G_m$) of the mix, Percentage of Air voids ($V_v$) in the mix, Percentage volume of bitumen ($V_b$) in the mix, Voids in mineral aggregate ($V_{MA}$) and Voids filled with bitumen ($V_{FB}$).

4. Results and Discussions

| Sample No. | 1  | 2  | 3  | 4  | 5  |
|------------|----|----|----|----|----|
| Binder content (%) | 5  | 5.5| 6  | 6.5| 7  |
| Bulk density (gm./cc) | 2.330| 2.332| 2.333| 2.335| 2.331|
| % Air voids | 5.3 | 4.71| .04| 3.37| 3.03|
| % VFB | 67.5| 71.76| 76.27| 80.56| 83.01|
| Stability (kg) | 790.26| 849.91| 973.179| 1064.01| 856.81|
| Flow (mm) | 2.31| 2.53| 2.92| .23| 3.81|
Table 5. Marshall Parameters of Samples with 0.3% Of Coconut fiber

| Sample no | Binder content (%) | 1   | 2   | 3   | 4   | 5   |
|-----------|--------------------|-----|-----|-----|-----|-----|
|           | Fiber content (%)  | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Stability (kg) | 934.25        | 1012.1 | 1141.86 | 1291.43 | 1105.16 |
| Flow (mm)    | 2.16           | 2.38  | 2.8  | 3.07| 3.63|
| Marshall Quotient | 432.52   | 425.25 | 407.8 | 420.66 | 304.45 |
| Bulk Density(gm./cc) | 2.319 | 2.321 | 2.323 | 2.324 | 2.320 |
| Air voids (%) | 5.63 | 4.91  | 4.25 | 3.58| 3.07|
| Vb (%)       | 10.91          | 11.95 | 12.89 | 13.938| 14.96 |
| VMA(%)       | 16.54          | 16.86 | 17.14 | 17.518| 18.03 |
| VFB(%)       | 65.96          | 70.87 | 75.2  | 79.56| 82.97|

Table 6. Marshall Parameters of Samples with 0.3% Of Banana fibers

| Sample no | Binder content (%) | 1   | 2   | 3   | 4   | 5   |
|-----------|--------------------|-----|-----|-----|-----|-----|
|           | Fiber content (%)  | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Stability (kg) | 901.81        | 976.6 | 1115.91 | 1229.34 | 1080.33 |
| Flow (mm)    | 2.2             | 2.43  | 2.84 | 3.14| 3.68|
| Marshall Quotient | 409.91   | 401.89 | 392.92 | 391.5 | 293.56 |
| Bulk Density(gm./cc) | 2.317 | 2.319 | 2.322 | 2.323 | 2.319 |
| Air voids (%) | 5.49 | 4.88  | 4.24 | 3.48| 3.01|
| Vb (%)       | 11.04          | 12.0  | 12.89 | 14.07| 15.09|
| VMA(%)       | 16.53          | 16.88 | 17.13 | 17.55| 18.1 |
| VFB(%)       | 66.78          | 71.0  | 75.24 | 80.17| 83.37|

4.1 Graphs

Graphs were plotted based on the experimental observations and referring those, the Optimum Binder Content (OBC) of the stabilized Marshall Mix for 0.3% of fibers (OFC) were obtained for each of the case.

Figure 1. Percentage bitumen vs. Stability.

Observing all the above test results, Figure 1 and recorded tables for samples with or without fibres, it is marked that with rise in bitumen content the stability value goes on increasing to a certain level, and then falls for all the cases. By using 0.3% coconut fibre and 6.5% bitumen content, the maximum
stability value found was 1291.43 kg and using 0.3% banana fiber and 6.5% bitumen content maximum stability obtained was 1229.34 kg. On analysis it is found that mix with fiber possess more stability value than mix without fiber and sample containing coconut fibre is the most stable one.

![Image](image_path)

**Figure 2.** Percentage bitumen vs Flow value.

Figure 2 shows that increasing bitumen content leads to increase in flow value in all cases but the rate of increase is higher at higher bitumen content. Samples with fiber possess lower flow value than samples without fiber.

![Image](image_path)

**Figure 3.** Percentage bitumen vs. Bulk specific gravity.

Figure 3 shows that the Bulk Density gradually increases up to a limit and then decreases with addition of bitumen. Addition of fiber leads to decrease in Bulk Density.
Figure 4 shows that due to networking effect of the fibre there is an increase in air voids in case of samples containing fibers. For all the cases the bitumen content and the Air voids are inversely proportional.

Figure 4. Percentage bitumen vs Air voids.

Figure 5 shows that with rise in binder content, the voids filled with bitumen goes on increasing and VFB is less for stabilized sample.

Figure 5. Percentage bitumen vs. VFB.

4.2. Optimum Bitumen Content
Observation shows that optimum binder content for SMA without fibre is 6.36% by weight of aggregate which is 5.95% by weight of the total mix, but it becomes 6.06% of total weight of mix when 0.3% of coconut fibre is added or the OBC becomes 6.46% by weight of aggregate. But for addition of 0.3% of banana fibre the OBC becomes 6.43%. All these values have been obtained by calculating the average value of bitumen content corresponding to 4% air voids, maximum density and maximum stability.
5. Conclusion

After proper analysis, it is concluded that bitumen pavement receives extra strength for use of well graded aggregates, shortage of such aggregate affects the paving industries. But use of coconut fibre can be taken as a solution to this shortage, at the same time its easy availability makes the process easy. Banana fibre can also be used with same purpose. From Marshall test it is noticed that 0.3% of fibre can bring adequate improvement in Marshall characteristics.

Conducting analytical study on the use of gap graded materials like SMA in Bituminous paving, it is concluded that adding coconut fiber in the mixture as a stabilizer to check the possibility of drain down of Bituminous in one hand and supplementing strength to the mixture in the other, is more efficacious in all respect. Both banana fiber and coconut fiber are easily acquired from the waste in profusion but on comparison after use, the experiment result shows that coconut fiber stabilized SMA has higher specific gravity and higher tensile strength. Though it is deciphered that whatever is the fiber the maximum Marshall Quotient, the maximum value of stability, and bulk specific gravity of SMA mixture is found at 0.3% fiber content, even the flow values of the mixture are located within the specified range of 2 to 4 mm, still the coconut fiber stabilized mixture is better as it provides a higher Marshall stability, hence its use is feasible and preferable in Indian context and condition.

Further studies are required to test the validity of the additives in the bituminous mixtures along with its effect on fatigue behavior and rutting characteristics.

References

[1] Asasutjarit C, Hirunlabh J, Khedari J, Charoenvai S, Zeghmati B and Shin U C 2007 Development of coconut coir-based lightweight cement board Construction Building Materials 21 277-88
[2] Aziz M, Paramasivam P and Lee S 1981 Prospects for natural fibre reinforced concretes in construction International Journal of Cement Composites Lightweight Concrete 3 123-32
[3] Bose S, Kamraj C and Nanda P 2006 Stone Matrix Asphalt (SMA)-A Long Life Pavement Surface
[4] Cook D, Pama R and Weerasingle H 1978 Coir fibre reinforced cement as a low cost roofing material Building Environmental Technology 13 193-8
[5] Li Z, Wang L and Wang X 2006 Flexural characteristics of coir fiber reinforced cementitious composites Fibers Polymers 7 286-94
[6] Ali M, Liu A, Sou H and Chouw N 2012 Mechanical and dynamic properties of coconut fibre reinforced concrete Construction Building Materials 30 814-25
[7] Ali M 2011 Coconut fibre: A versatile material and its applications in engineering Journal of Civil Engineering Construction Technology 2 189-97
[8] Ali M, Li X and Chouw N 2013 Experimental investigations on bond strength between coconut fibre and concrete Materials Design 44 596-605
[9] https://skmobifiles.wordpress.com/2017/04/morth-specifications-for-road-bridge-works-5th-revision-by-sk.pdf
[10] Paramasivam P, Nathan G and Gupta N D 1984 Coconut fibre reinforced corrugated slabs International Journal of Cement Composites Lightweight Concrete 6 19-27
[11] Reis J 2006 Fracture and flexural characterization of natural fiber-reinforced polymer concrete Construction building materials 20 673-8
[12] Subramani T 2012 Experimental Investigations on Coir fibre reinforced bituminous mixes Strain 2 4-5