ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

# A STUDY ON PERFORMANCE AND COMPARISON OF STONE MATRIX ASPHALT WITH CELLULOSE FIBRE AND COIR FIBRE

**T.ANITH KUMAR[1], P. SATEESH[2]**

[1]Assistant Professor, Department Of Civil Engineering, Malla Reddy Institute Of Technology, Maisammaguda,Dulapally,Secunderabad,Telangana,500100

[2]Assistant professor, Department of Civil Engineering, Malla Reddy institute of technology, Maisammaguda,Dulapally,Secunderabad,Telangana,500100

## ABSTRACT

The stone matrix asphalt (SMA) mixture is a gap-graded mix which is characterized by high coarse aggregates, high asphalt contents and fiber additives as stabilizers. Due to stone to stone contact and presence of high filler content, it acts as a stiff matrix and is best suitable for high volume roads and urban intersections where braking effects are more. In general, carbon fibers are added in SMA mixes to avoid oozing of bitumen from the mix. In the present study, in addition to the carbon, coir fibers will be added to the SMA mixes and its properties will be evaluated. Since, the coir fibers are easily available in India and comparatively cheap, it is decided to use in the current investigation. Detailed laboratory investigations will be carried out by preparing asphalt concrete mixtures by adding two types of fibers (carbon and coir) with dosages of 0.3%, 0.4% and 0.5% by weight of total mix. Volumetric properties of the mixes will be determined and various strength tests such as marshal stability will be conducted. On the basis of above tests conclusions will be drawn on suitability of coir fibers in place of cellulose fibers.

***Keywords:*** stone matrix asphalt (SMA), the coir fibers, two types of fibers (carbon and coir) , marshal stability,etc.

## I. INTRODUCTION

India being the second largest growing economy country in the world, in par with other developed activities, road infrastructure is developing at a very fast rate. Large scale road infrastructure development projects like National Highway Development Project (NHDP) and Pradhan Manthri Gram Sadak yojna (PMGSY) are in progress. The spurt in the growth of traffic and overloading of vehicles decreases the life span of roads laid with conventional bituminous mixes. The spurt in the growth of traffic and overloading of vehicles decreases the life span of roads laid with conventional bituminous mixes. This also leads to the reduction in the riding quality resulting in exorbitant vehicle operating cost and frequently maintenance interventions due to premature failure of pavements.

### Types of Asphalt surfacing

There are three major types of asphalt surfacing, characterized by a mixture of bitumen and stone aggregate. These are Dense Graded asphalt, Stone Mastic Asphalt and Open Graded Asphalt.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

Stone mastic asphalt (SMA) is a stone-on-stone like skeletal structure of gap graded aggregate, bonded together by mastic, which actually is higher binder content, filler and fibre to reduce the binder drain. This structure improves the strength and the performance of SMA even higher than the dense graded and open graded asphalt mixtures. High percentage of binder content is important to ensure the durability and laying characteristics of SMA.

SMA is best explained as two-component hot mix asphalt HMA which comprises a coarse aggregate skeleton derived from a gap-graded gradation and a high bitumen content mortar. Since 1960s, Stone Mastic Asphalt (SMA) pavement surfaces have been used successfully in Germany on heavily trafficked roads. In recognition of its excellent performance a national standard was set in Germany in 1984. Since then, because of its excellent performance characteristics, the use of SMA increased in popularity amongst the road authorities and asphalt industry.

**(a) Dense graded asphalt (b) Stone Matrix Asphalt (c) Dense-Graded HMA (left) vs. SMA (right)**

**Difference between SMA and Conventional mixes**

SMA is successfully used by many countries in the world as highly rut resistant bituminous course, both for binder (intermediate) and wearing course. The major difference between conventional mixes and SMA is in its structural skeleton .The SMA has high percent about 70-80 percent of coarse aggregate in the mix . On the other hand, conventional mixes contain about 40-60 percent coarse aggregate. They does have stone to stone contact, but it often means the larger grains essentially float in a matrix composed of smaller particles, filler and asphalt content .The stability of the mix is primarily controlled by the cohesion and internal friction of the matrix which supports the coarse aggregates

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

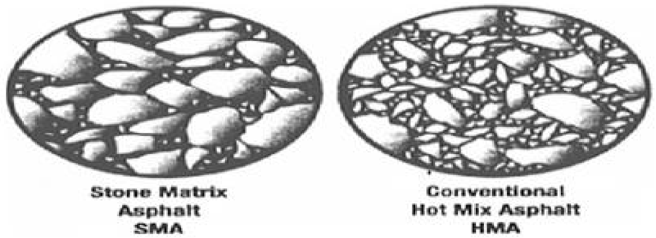



**Fig 1.2**

Main differences of SMA and Bituminous mix (Bose et al. 2006)

| Properties | SMA | BC |
|---|---|---|
| Definition | SMA is a gap graded mix which consists high amount of coarse aggregates hardly bonded by a strong asphalt matrix consisting of fine aggregate, filler, bitumen and stabilizing additives | BC consists of well graded coarse and fine aggregate, filler and bitumen |
| Mass of Coarse Aggregate Content (%) | 75 – 80 | 50-60 |
| Mass of Fine Aggregate (%) | 20 – 25 | 40 – 50 |
| Mass of Filler content (%) | 9 – 13 | 6 – 10 |
| Binder Type (%) | 60/70, PMB- 40 | 60/70, 80/100 and modified binders |
| Minimum binder content by weight of mix (%) | >6.5 | 5 – 6 |
| Stabilizing Additives by weight of mix (%) | 0.3 – 0.5 | ----- |
| Air Voids (%) | 3– 4 | 3– 6 |
| Layer Thickness, mm | 25-75 | 30-65 |

## OBJECTIVES FOR THE STUDY

To investigate the performance of Stone Matrix Asphalt (SMA), with the usage of Cellulose fibre and coconut (coir) fibre under the influence of change in nominal maximum aggregate sizes based on Indian specifications. The lists of objectives are stated below

- Comparison of drain down results at varying fibre contents with 7% bitumen at 160C and 170C temperature.
- Comparison of stability, flow and volumetric property of SMA mixes, using VG-30, Cellulose fibre and coir fibre by using Marshall Methods.
- Based on cost effectiveness either coir fibre or cellulose fibre to be used.

Finally to understand the effect of significant changes in characteristics of the mixes due to Cellulose fibre and Coir fibre in SMA mixtures.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

## II. LITERATURE REVIEW

Majority of the roads all over the world are made up of flexible pavements. Flexible pavements consist of a bituminous layer on the surface course and sometimes in base course followed by granular layers in base and sub base courses over the subgrade. The most common type of flexible pavement surfacing used in India is a premix bituminous material, commonly called outside as Hot Mix Asphalt (HMA). HMA is a mixture of coarse and fine aggregates and asphalt binder. HMA mixtures are mixed, placed and compacted at higher temperature. The aggregates used in the lower layer are to prevent rutting and the aggregates which are used in the top layer are generally selected on the basis of their friction properties and durability. There are several types of HMA mixes. These include conventional Dense Graded Mixes (DGM), Stone Matrix asphalt (SMA) and various Open graded HMA. The HMA mixes differ from each other mainly in maximum aggregate size, aggregate gradation and binder content or type of binder used.

The growth of vehicular loadings necessitated us to choose a more durable and rut resistant pavements .These asphalt mixtures behave as per temperature and wheel load stresses causing deformations due to the repetitive loadings of vehicles. So, such structural changes are sensitive by performances given by surface layers (**Hadiwardoyo 2013**). In general the damage to highways occurs from surface layers which are critical to type of aggregate, binder and other stabilizers we chose for the pavement construction. These structural failures were seen as surface cracks like alligator or block cracking, rutting, potholes (**Huang 2009**) making the pavement condition severe and un-serviceable.

**Brief History of SMA**

The Stone matrix asphalt (SMA) or the "Splittmastixasphalt" which was familiar in Germany during 1960's. A German engineer Dr. Zichner who is manager of Central Laboratory for Road Construction at the Strabag Bau AG was its designer (**Blazejowski 2011**). So, during these sixties the tendency in surface courses in Germany was to use "glass asphalt" (mastic asphalt) and also the asphaltic concrete having low coarse aggregate fractions, higher air voids and low bitumen content (**Sehgal et al. 2011**) making its performance degrade especially with studded tyres in winter as seen in Fig 2.1. Due to the poor mix qualities the wearing courses were not able to resist these studded tyres effecting the pavement service period

**Potential development all over the world**

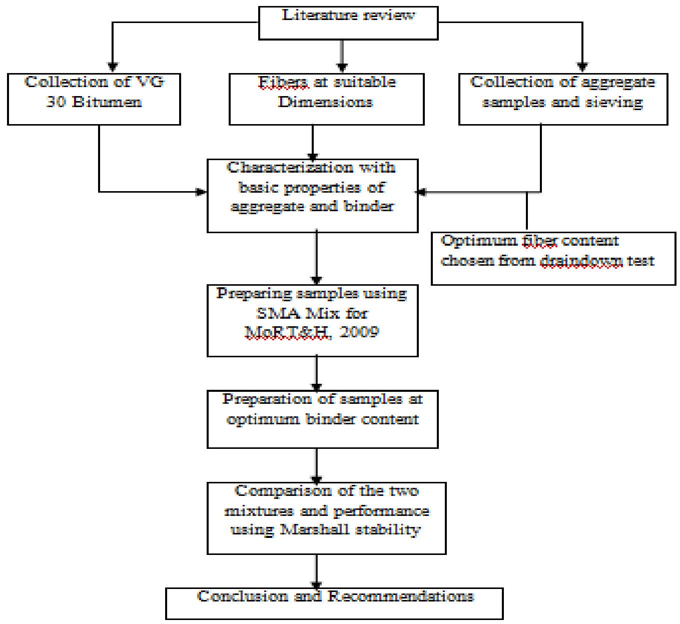
The surface courses made with asphaltic concrete (AC) mix showed lower level performances as compared to the developed SMA mixtures. The modern highways are pertained to increased speed, axle loadings, traffic density causing pavement distresses such as rutting, ravelling and cracking (**Thulasirajan et al. 2011**). The Stone matrix asphalt (SMA) was renowned with research from 1975, its concept became famous observing the performances with rutting and durability. Presently SMA was considered as supreme for its operation for heavy-duty asphaltic pavements which need improvised resistance to pavement failures and service life.

## III.METHODOLOGY

The present research study is focused on the gap-graded hot asphalt mix called the Stone matrix asphalt (SMA), which is designed to maximize the resistance against the permanent deformations using the stone-on-stone aggregate skeleton. The volumetric properties of an asphalt mix depend on the kind of gradation adopted. It is difficult to achieve the exact mid gradation from a quarry having wide size range in aggregates. Hence it's essential to study the characteristics of SMA over changes in gradation based on the fatigue and rutting characteristics. For this study, comparison between two aggregate gradations namely, Chinese gradation adopted in airfields (Prowell et al. 2009) and the MoRT&H, 2009 gradation having the nominal aggregate size of 16mm and 13.2mm respectively are chosen. To overcome the problem of drain down the natural stabilizer which is biodegradable, abundantly, economically available coir fibre is chosen using the mechanical tests of samples its feasibility was verified. Using the conventional binder VG-30 (Al-Hadidy et al. 2009) samples prepared with varying contents 5.5%- 7.0% (by weight of mineral aggregate) and with fixed fibre content of 0.3% (by weight of mix). The Marshall mix design procedure with aid of Super pave gyratory compaction for the significant air void percentage was used to optimize asphalt content for both type of gradations. Christo Ananth et al.[10] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

The optimum binder content are found at 3-4% air voids. The Table 3.1 and Table 3.2, mentions the guidelines for SMA mix design requirements as per IRC:SP:53-2008 and MoRT&H,2009 respectively, based on these, design of SMA mixtures is carried out. The experimental research approach followed in this study shown in the Fig 3.1. In the preliminary step the properties of aggregate and asphalt are evaluated. Next the feasible fibre content was evaluated for the two gradations using the drain down testing methodology. In the next stage the optimization of mix is done. Later, the comparison of both mixes using the performance tests such as Marshall Stability, moisture susceptibility, fatigue and rutting

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017




**SMA mix requirements as per (MoRTH-2009 and IRC:SP:53-2008)**

| Property | Criteria |
|---|---|
| Design air voids , % | 4 |
| Bitumen , % | 5.8 minimum |
| Voids in Mineral Aggregates (VMA), % | 17 minimum |
| Voids in Coarse Aggregates mix (VCAMix), % | Less than Voids in Coarse Aggregates (dry rodded) (VCADRC) |
| Asphalt draindown, % AASHTO T 305 | 0.30 maximum |
| Tensile Strength Ratio (TSR), % AASHTO T 283 | 80 minimum |

## MATERIALS

### 1 Aggregate

The aggregate (both Coarse and fine) used in this study was brought from the quarry located near village Belman District. Udupi, Karnataka. These aggregates used in SMA should be highly durable, strong and tough to resist heavy loads

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

**Coarse Aggregate:** The coarse aggregates were of crushed granite rock retained on 2.36 mm sieve. In order to ensure proper stone-on-stone contact the passing 4.75mm sieve is ensured to be less than 30% in the adopted gradation (**Brown 1992**).

**Fine Aggregate:** A fine aggregate is the passing 2.36 mm sieve and retained on 0.075 mm sieve which are ensured to be clean, durable, and free of organic or other deleterious substances. In the SMA mixes the passing 0.075mm sieve is recommended to be 8-10%, this filler play a role in volumetric properties of mix and optimum asphalt content which significantly distinguishes SMA from conventional mixes. The properties of the aggregate are shown in Table 3.2 and compared with the standard specifications.

**Aggregate gradation:** The aggregate gradations influence in the present study is compared between the MoRT&H, 2009 and the Chinese airfield gradation specifications. The MoRT&H gradation i.e., the Indian gradation having the nominal maximum aggregate size of 19mm has been described in Table 3.3 and gradation curve was also shown as in Fig

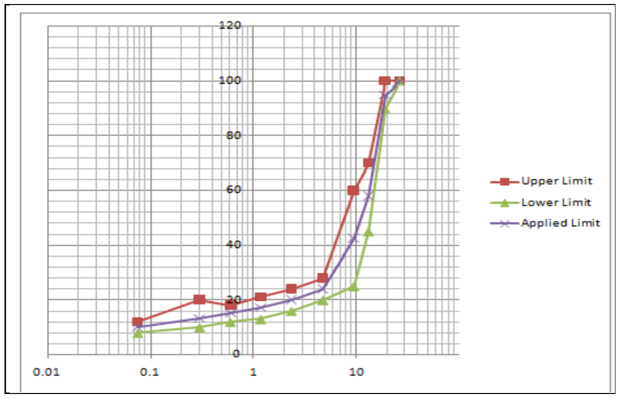
**Physical properties of the aggregate**

| Property | Test | Results | Test method | MoRT&H Specifications (2009) |
|---|---|---|---|---|
| Particle shape | Flakiness and Elongation Index (combined) | 21.75% | IS 2386 Part I | 30% maximum |
| Strength | Los Angeles Abrasion Value | 24.62% | IS 2386 Part IV | 25% maximum |
| | Aggregate Impact Value | 20.39% | | 24% maximum |
| Toughness | Aggregate Crushing Value | 22.06% | IS 2386 Part IV | 30% maximum |
| Specific Gravity | 20 mm | 2.654 | IS 2386 Part III | 2.5 minimum |
| | 10 mm | 2.656 | | |
| | Stone Dust | 2.676 | | |
| Water absorption | 20 mm | 0.104 | IS 2386 Part III | 2% maximum |
| | 10mm | 0.095 | | |
| | Stone Dust | 0.798 | | |

**Aggregate gradation as per MoRT&H,2009**

| Designation | 19 mm SMA |
|---|---|
| Course where used | Binder (Intermediate) Course |
| Nominal aggregate size | 19 mm |
| IS Sieve (mm) | Cumulative % by weight of total aggregate passing |
| 26.5 | 100 |
| 19 | 90 – 100 |
| 13.2 | 45 – 70 |
| 9.5 | 25 – 60 |
| 4.75 | 20 – 28 |
| 2.36 | 16 – 24 |
| 1.18 | 13 – 21 |
| 0.600 | 12 – 18 |
| 0.300 | 10 – 20 |
| 0.075 | 8 – 12 |

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017




**SMA grain size distribution curve for the MoRT&H,2009, Indian specification**

The filler is the 0.075mm passing, where for the total 10% filler content, 2% of hydrated lime and 8% of the granite dust is used for sample preparation. The filler shall be graded within the limits as in below Table

**Graduation requirements of filler (IRC:SP:79-2008)**

| IS Sieve (mm) | Cumulative % passing by weight of total aggregate |
|---|---|
| 0.600 | 100 |
| 0.300 | 95 – 100 |
| 0.075 | 85 – 100 |

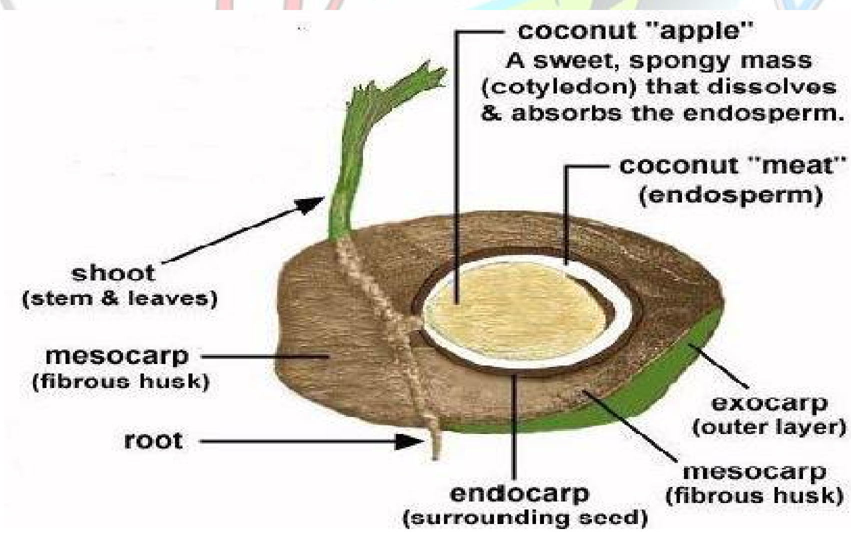



**Illustration of general coconut**

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

**Properties of coir fibre**

| Property | | Value |
|---|---|---|
| Colour | | brown and golden brown |
| single fiber | average length | 10 -20mm |
| | average diameter | 0.09-0.12mm |
| | Aspect ratio (l/d) | 120-160 |
| moisture content | | >10%(by weight) |

**Physical appearance of coir used in the study**

## IV. RESULTS AND DISCUSSIONS

### Study approach

In this study the research has been emphasized on the optimum quantity of coir fibre to be used in the preparation of asphalt mixes for the comparative analysis between two opted gradations. The coir fibres length are fixed in a range of 10-20 mm (to prevent lumps forms during mixing), but the percentage fibre (by weight of total mix) is decided on draindown test results. Maintaining the fibre length more than 20mm further increase air gap between aggregates degrade the mix behaviour (Thulasirajan et al.2011). Later using the obtained optimal fibre quantity with constant length is used in the mixes of nominal aggregate sizes of 13.2 mm Indian and 16 mm Chinese SMA Gradations for the performance testing. The experiments carried out on SMA mixes mentioned in previous chapter, with the present mixes results and observations are discussed in this chapter.

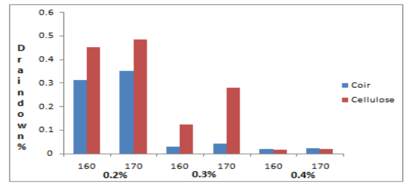
### Drain down of binder

Drain down values of SMA mix (Cori fibre)   Drain down values of SMA mix (Cellulose fibre)

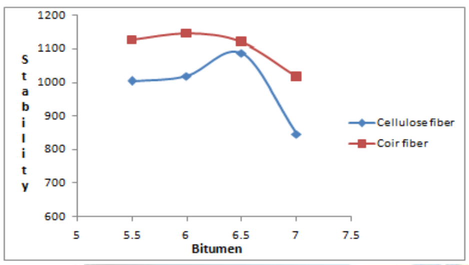
ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

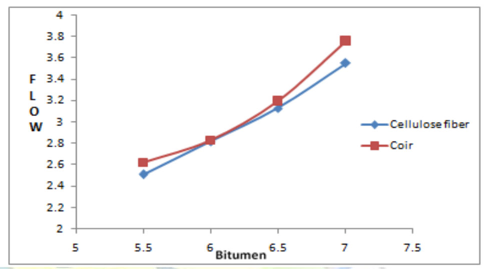
| Fiber Content % | Draindown % | | |
|---|---|---|---|
| | Draindown at 160°C | Draindown at 170°C | MoRT&H Specification |
| 0.2 | 0.3124 | 0.3524 | 0.3 Maximum |
| 0.3 | 0.0279 | 0.0421 | |
| 0.4 | 0.0185 | 0.0213 | |

| Fiber Content % | Draindown % | | |
|---|---|---|---|
| | Draindown at 160°C | Draindown at 170°C | MoRT&H Specification |
| 0.2 | 0.4521 | 0.4853 | 0.3 Maximum |
| 0.3 | 0.1229 | 0.2820 | |
| 0.4 | 0.0164 | 0.0194 | |




### Marshall Properties




### Volumetric properties

### Properties of SMA samples prepared using Coir fibre

| Property | Bitumen content (by weight of aggregate) | | | |
|---|---|---|---|---|
| Nominal aggregate size of 19 mm , Indian SMA | 5.50% | 6.00% | 6.50% | 7.00% |
| Marshall stability (Kgs) | 1126.8 | 11046.6 | 1121.4 | 1098 |
| Flow Value (mm) | 2.62 | 2.83 | 3.2 | 3.56 |
| Bulk density (gm/cc) | 2.373 | 2.517 | 2.343 | 2.36 |
| Volume of voids Vv (%) | 5.611 | 4.21 | 3.721 | 3.11 |
| Voids in Mineral Aggregate VMA (%) | 17.702 | 17.733 | 18.068 | 18.706 |
| Void filled with bitumen VFB (%) | 68.303 | 76.258 | 79.406 | 83.374 |
| Marshall Quotient (Kgs/mm) | 430.076 | 405.159 | 350.438 | 308.427 |
| VCA Mix | 23.313 | 19.039 | 24.989 | 24.8 |
| VCA Mix/ VCA Dry | 0.64 | 0.53 | 0.69 | 0.69 |
| Optimum Bitumen content (%) | 6.23% | | | |

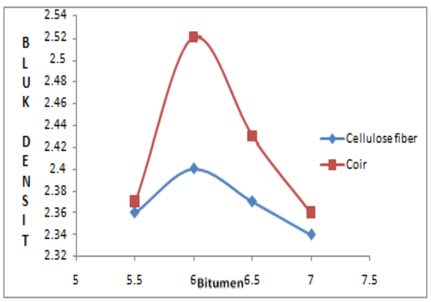
### Properties of SMA samples prepared using Cellulose fibre

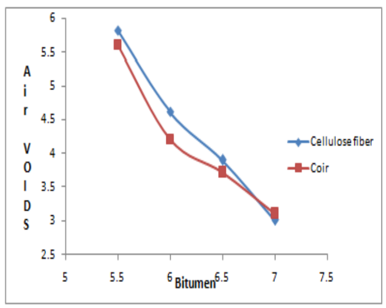
| Property | Bitumen content (by weight of aggregate) | | | |
|---|---|---|---|---|
| Nominal aggregate size of 19 mm , Indian SMA | 5.50% | 6.00% | 6.50% | 7.00% |
| Marshall stability (Kgs) | 1004.4 | 1018.8 | 1087.2 | 846 |
| Flow Value (mm) | 2.51 | 2.82 | 3.31 | 3.55 |
| Bulk density (gm/cc) | 2.357 | 2.405 | 2.373 | 2.343 |
| Volume of voids Vv (%) | 5.821 | 4.62 | 3.9 | 3.01 |
| Voids in Mineral Aggregate VMA (%) | 17.11 | 17.581 | 19.32 | 19.464 |
| Void filled with bitumen VFB (%) | 65.978 | 73.721 | 79.81 | 84.375 |
| Marshall Quotient (Kgs/mm) | 400.159 | 361.277 | 328.459 | 238.350 |
| VCA Mix | 23.831 | 22.64 | 24.028 | 25.35 |
| VCA Mix/ VCA Dry | 0.66 | 0.63 | 0.66 | 0.70 |
| Optimum Bitumen content (%) | 6.43% | | | |

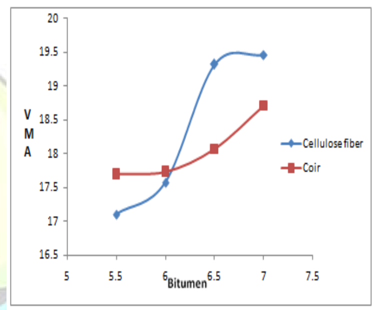
ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

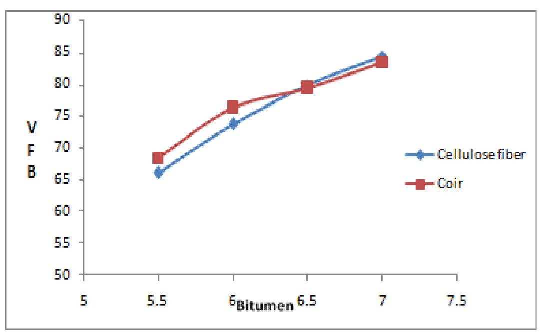
**Properties of SMA mix at Optimum binder content**

| Property | Type of Fiber | |
|---|---|---|
| | Coir | Cellulose |
| Bulk density (gm/cc) | 2.437 | 2.39 |
| Voids in Mineral Aggregate VMA (%) | 17.887 | 18.381 |
| Void filled with bitumen VFB (%) | 77.706 | 74.43 |
| Marshall stability (Kgs) | 1135.008 | 1026.643 |
| Flow Value (mm) | 9.528 | 10.093 |
| Marshall Quotient (Kgs/mm) | 379.987 | 328.459 |




## V. CONCLUSIONS

The basic purpose of this study was to evaluate the use of coconut (coir) fibre instead of cellulose fibre. As the coir fibre is locally available material more over its cost is too less comparing with cellulose fibre. Thus, the results of the use of 10-15mm length fibres with along with conventional VG-30 graded binder in the SMA can be summarized as follows:

- The fibre content of 0.3% was found to be optimum satisfying the drain down of the binder and also at the Optimum binder content of bitumen.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

- The optimum binder was evaluated to be 6.23% and 6.43% for Coir and Cellulose fibre respectively with 5.5% as minimum binder content to prevent fat spots. The binder content required was more in Cellulose fibre.
- The percent drain down at OBC the range was 0.0021% - 0.0648 %, concluding that Coir fibre to be better then Cellulose fibre.
- The stability value at OBC and 0.3 % fibre content was 1135.00Kgs and 1026.643Kgs for the Coir and Cellulose respectively i.e., almost 9.55% increase in stability as compared to Cellulose. The flow values are 3.56mm and 3.55mm for Coir and Cellulose fibre respectively as prescribed standards in range of 2 - 4 mm.
- Hence by adding the coir fibre the drain-down can be arrested. The role of aggregate skeleton played an important role in behaviour of the mixes in the stability, tensile strength and Coir fibre will be cost effectiveness rather then cellulose fibre.

**SCOPE FOR FURTHER RESEARCH**

- To check the feasibility of SMA mixes using coir fibre by choosing different nominal aggregate sizes from the specifications such as in IRC:SP:2008, NAPA , NCHRP 425 especially adopted in United States and German.
- To study effect of fatigue, strength properties on performance of SMA using modified bitumen’s like CRMB, PMB etc.
- Study the variation in performance of different dimensions and content in the SMA.

**REFERANCES**

[1] Abtahi, S.M.,M.Sheikhzadeh., S.M, Hejazi. (2010). "Fibre-reinforced asphalt-concrete- A review." *Construction and Building Materials,24 (6)*, 871-877.

[2] Ahmed, M.A., Attia, M.I.E. (2013). "Impact of aggregate gradation and type on Hot mix asphalt rutting in Egypt." *Engineering research and applications,3(4)*, 2249-2258.

[3] Al-Hadidy, A.I., Tan, Y.Q. (2009). "Mechanistic analysis of ST and SBS-modified flexible pavements."*Construction Building Materials,23*, 2941-2950.

[4] Al-Hadidy,A.I.,Tan, Y.Q. (2011). "Performance of the SMA mixes made with the various binders." *Construction and Building Materials,25*, 3668-3673.

[5] ASTM D6390. (2005). ″Standard test method for determination of drain down characteristics in Uncompacted Asphalt mixtures.″ ASTM International, formerly known as the American Society for Testing and Materials,USA.

ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Issue 3, March 2017

[6] ASTM D2041. (2011). "Standard test method for Theoretical Maximum specific gravity and density of Bituminous paving mixtures." ASTM International, formerly known as the American Society for Testing and Materials,USA.

[7] ASTM D6931. (2012). "Standard test method for Indirect tensile (IDT) strength of bituminous mixtures." ASTM International,formerly known as the American Society for Testing and Materials,USA.

[8] Beena, K.S., Bindu, C.S. (2011). "Coir fibre as a stabilizing Additive in Stone Matrix Asphalt."*International Journal of Earth sciences and engineering,4(1)*, 165-177.

[9] Behbahani, H., Nowbhakt, S., Fazaeli, H., & Rahmani, J. (2009). "Effects of fibre type and content on rutting performance of Stone matrix asphalt." *Applied sciences,9(10)*,1980-1984.

[10] Christo Ananth, S.Esakki Rajavel, S.Allwin Devaraj, M.Suresh Chinnathampy. "RF and Microwave Engineering (Microwave Engineering).", ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-5-8, Volume 1,June 2014, pp:1-300.

[11] Bernardita, Lira., Denis, J., Bjorn, B. (2013). "Gradation-based framework for asphalt mixture." *Materials and Structures,46(8)*, 1401-1414.

[12] Binu, S.M.,Binu , S.S. (2009). "Effect of Gradation of Aggregates on the Properties of Stone Matrix Asphalt." *10th National Conference on Technological Trends.* Trivandrum, 171-176.

[13] Birgisson,B., Ruth , BE. (2001). *"Development of tentative guidelines for the selection of aggregate gradations for hot mix asphalt."* ASTM STP 1412. American Society for Testing and Materials,West Conshohocken.

[14] Bitumina- hitech pavement binders. (2006). "Products and services." Bitumina hitech pavement binders,http://www.bitumina.co.uk/our-products.html (Nov 15, 2013)

[15] Blazejowski, K. (2011). *"Stone Matrix Asphalt Theory and Practice."* New York: CRC Press Taylor & Francis Group.

[16] Brown, E., & Cooley, L. (1999). *"Designing Stone Matrix Asphalt mixtures for Rut resistant Pavements."* NCHRP Report 425, National Cooperative Highway Research Program,Transportation research Board,Washington, D.C; USA.

[17] Brown, E.R. (1992). *"Experience with Stone matrix asphalt in the United States."* National Asphalt Pavement Association (NCAT) , Auburn University, Albama.

[18] Brown, E.R., Manglorkar, H. (1993). *"Evaluation of Laboratory properties of SMA mixtures."* NCAT Report 93-05,National Centre for Asphalt Technology,USA.

[19] Brown, E.R., Haddock, J.E. (1997). *"A method to ensure stone-on-stone contact in stone matrix asphalt."* National centre for Asphalt technology,Auburn university,NCAT Report 97-2.