American Journal of Science and Learning for Development

ISSN 2835-2157
Volume 2 | No 6 | Jun -2023

An Investigation of Asphalt Mixtures Using a Naturally Occurring Fibre

Niranjan Kumar[1], Pappu Kumar [2], Ajay Kumar[3], Ravi Kumar[4]

[1] Research Scholar, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India
[2,3]Assistant Professor, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India
[4] Lecturer, Department of Civil Engineering, Sandip Foundation, Madhubani, Bihar, India

Abstract: *In this study, the researchers investigated the effects of using a locally available fiber called Sisal fiber as a stabilizer in Stone Matrix Asphalt (SMA) and as an additive in Bituminous Concrete (BC). The composition of a bituminous mixture typically includes coarse aggregate, fine aggregate, filler, and binder. Hot Mix Asphalt (HMA) refers to a bituminous mixture where all the constituents are mixed, placed, and compacted at high temperatures. SMA is a type of HMA that is gap graded, while BC is a Dense Graded mix (DGM) also known as Bituminous Concrete. SMA requires stabilizing additives such as cellulose fibers, mineral fibers, or polymers to prevent the drainage of the mix. The researchers aimed to study the impact of adding Sisal fiber, a naturally available fiber, as a stabilizer in SMA and as an additive in BC. To prepare the mixes, the researchers followed the aggregate gradation specified by MORTH (Ministry of Road Transport and Highways). The binder content was varied from 4% to 7%, and the fiber content ranged from 0% to a maximum of 0.5% of the total mix. In the preliminary study, fly ash was found to yield satisfactory Marshall Properties, so it was used in subsequent mixes. Using the Marshall Procedure, the Optimum Fiber Content (OFC) for both BC and SMA mixes was determined to be 0.3%. Similarly, the Optimum Binder Content (OBC) for BC and SMA was found to be 5% and 5.2% respectively. The BC and SMA mixes prepared at these optimum levels were then subjected to various performance tests, including Drain Down test, Static Indirect Tensile Strength test, and Static Creep test, to evaluate the effects of fiber addition on mix performance. The study concluded that the addition of Sisal fiber improves the mix properties, such as Marshall Stability, Drain Down characteristics, and indirect tensile strength, for both BC and SMA mixes. It was also observed that SMA performed better than BC in terms of indirect tensile strength and creep characteristics.*

Keywords: *Bituminous Concrete (BC), Stone Matrix Asphalt (SMA), Sisal Fiber, Marshall Properties, Static Indirect Tensile Strength, Static Creep.*

1. INTRODUCTION

Highway construction requires a significant amount of investment, and it is crucial to have precise engineering design to save costs and ensure reliable performance of the highway. In flexible pavement engineering, two main considerations are pavement design and mix design. This study specifically focuses on mix design considerations. A well-designed bituminous mix is expected to possess several key qualities. It should be strong, durable, resistant to fatigue and permanent deformation, environmentally friendly, and cost-effective, among other requirements. Mix designers aim to achieve these qualities by conducting various tests on mixes with different proportions, ultimately selecting the best mix design. The present research work aims to address some of the challenges associated with bituminous mix design and explore the current research trends in this field. By identifying and addressing these issues, researchers aim to improve the overall quality and performance of bituminous mixes used in highway construction.

2. OBJECTIVE OF BITUMINOUS MIX DESIGN

Asphaltic or Bituminous concrete is composed of a mixture of aggregates that are continuously graded, ranging from maximum size (usually less than 25 mm) down to fine filler particles smaller than 0.075 mm. An adequate amount of bitumen is added to the mix to ensure that the compacted mixture is impermeable and possesses desirable dissipative and elastic properties. The goal of bituminous mix design is to determine the appropriate proportions of bitumen, filler, fine aggregates, and coarse aggregates in order to create a mix that is both workable and meets certain criteria for strength, durability, and cost-effectiveness. The mix design process aims to achieve the following objectives:

- Sufficient bitumen content to ensure the pavement's durability.
- Adequate strength to resist shear deformation caused by traffic, particularly at higher temperatures.
- Appropriate air voids within the compacted bitumen to allow for additional compaction from traffic.
- Sufficient workability to enable easy placement without segregation of the mix components.
- Sufficient resistance to prevent premature cracking resulting from repeated bending by traffic.
- Adequate resistance at low temperatures to avoid shrinkage cracks.

By proportioning the various components effectively, the mix design seeks to produce a bituminous mix that satisfies these requirements and yields a pavement that is durable, structurally sound, and capable of withstanding the demands of traffic under various conditions.

3. CHARACTERISTICS OF MATERIAL USED IN BITUMINOUS MIX

Mineral Aggregate: Bituminous mixes can utilize different types of mineral aggregates obtained from natural sources such as glacial deposits or mines. These natural aggregates can be used as-is or undergo further processing. Additionally, industrial by-products like steel slag or blast furnace slag may be incorporated to enhance mix performance. Reclaimed bituminous pavement is also a valuable source of aggregate. Aggregates play a crucial role in providing strength to asphalt mixtures, with coarse aggregates comprising a significant portion of Stone Matrix Asphalt (SMA) mixes. The higher proportion of coarse aggregate in SMA forms a skeleton-like structure that improves stone-to-stone contact, resulting in superior shear strength and resistance to rutting compared to Bituminous Concrete (BC). Federal Highway Administration guidelines recommend aggregates with cubic shape, rough texture to resist rutting and movements, hardness to withstand heavy traffic loads, resistance to polishing, and high abrasion resistance.

Mineral Filler: Mineral fillers have a notable impact on the properties of SMA mixtures. They enhance the stiffness of the asphalt mortar matrix and affect workability, moisture resistance, and aging characteristics of Hot Mix Asphalt (HMA) mixes. Various types of mineral fillers, such as stone dust, ordinary Portland cement (OPC), slag cement, fly ash, or hydrated lime, are used in SMA mixes.

Binder: Bitumen serves as the binding agent in bituminous mixes, providing durability. The behavior of bitumen influences the performance of the mixture, including temperature susceptibility, visco elasticity, and aging. Bitumen exhibits different properties depending on temperature and loading time. It becomes stiffer at lower temperatures and under shorter loading periods. Bitumen should be treated as a visco elastic material, as it demonstrates both viscous and elastic properties at normal pavement temperatures. At low temperatures, it behaves like an elastic material, while at high temperatures; it exhibits the characteristics of a viscous fluid.

4. LITERATURE REVIEW

Mogawer and Stuart (1996) The research conducted by Mogawer and Stuart (1996) focused on investigating how mineral fillers impact the properties of Stone Matrix Asphalt (SMA) mixtures. They carefully selected eight mineral fillers based on their performance and gradation characteristics. The evaluation of SMA mixtures involved assessing several key properties, including drain down of the mastic, rutting resistance, resistance to low-temperature cracking, workability, and susceptibility to moisture damage.

Mustafa Karasahin et al. (2006) In their study, Mustafa Karasahin et al. (2006) utilized waste marble dust obtained from the shaping process of marble blocks, as well as limestone, as fillers in bituminous mixtures. The researchers determined the optimum binder content using the Marshall Test, and the results were promising, indicating positive outcomes for the mixtures.

Yongjie Xue et al. (2008) In their research, Yongjie Xue et al. (2008) investigated the use of municipal solid waste incinerator (MSWI) fly ash as a substitute for fine aggregate or mineral filler in stone matrix asphalt (SMA) mixtures. They conducted a comparative analysis of the performance of the designed mixes using both Superpave and Marshall Mix design procedures.

Jony Hassan et al. (2010) Jony Hassan et al. (2010) conducted a study to examine the impact of utilizing waste glass powder as mineral filler on the Marshall properties of stone matrix asphalt (SMA). They compared the performance of SMA mixtures containing waste glass powder with mixtures where limestone and ordinary Portland cement were used as fillers, varying the filler content between 4% and 7%.

Brown and Mallick (1994) employed viscosity grade binder AC-20 for their investigation of the mixture design-related SMA characteristics. In 1996, Mogawer and Stuart also employed AC-20 binders.

Putman et al. (2004) employed PG 76-22 performance grade binder to research the SMA's physical characteristics. They discovered that bitumen treated with polymers performs better than unmodified bitumen in terms of deformation.

Sharma et al. (2004) modified bitumen with 80/100 penetration grade using natural rubber powder. Natural Rubber Modified Bitumen (NRMB) is how they referred to it. For their experiment, Kamaraj et al. (2006) employed 60/70 grade bitumen and SBS modified bitumen (PMB-40) in SMA.

Chiu and Lu (2007) examined if Asphalt Rubber (AR) might be used as a SMA binder. They combined tyre rubber (GTR) and AC-20 asphalt to create this AR. It was known as AR-SMA. The effectiveness of AR-SMA was assessed based on its susceptibility to moisture. In terms of moisture susceptibility, it was discovered that the AR-SMA combinations did not significantly vary from the traditional SMA mixtures. Additionally, it was shown that when this AR was added to the mix, no fibre was required to stop drain down.

Brown and Manglorkar (1993) compared SMA and DGM utilising two types of aggregate (granite and regional siliceous gravel), as well as cellulose and mineral fibre in SMA, and performed several tests such as the Marshall test, Drain down test, Indirect tensile strength test, and resilient modulus. They discovered that the high proportion of coarse aggregate in SMA mixtures creates a skeleton-like structure that offers improved stone-on-stone contact and good rutting resistance. Under severe traffic loads and high tyre pressure, SMA has demonstrated strong plastic deformation resistance. It also has strong low temperature qualities. Additionally, SMA has a rough texture that offers strong friction qualities after traffic has eroded the surface coating of the binder.

Brown (1994) Drain down in SMA is impacted by type of filler, type of stabiliser, and amount of stabiliser (higher the amount of stabiliser lower the drain down), according to research on SMA employing various types of filler and stabiliser. SMA mixes have a higher optimal binder content than DGM.

Bradely et al. (2004) study of waste fibre use in stone matrix asphalt mixes. To increase the strength and stability of the combination in comparison to cellulose fibre, they utilised scrap tyres, carpet fibre, polyester fibre, and waste yarn. They discovered that carpet fibre and used tyres work well to stop excessive SMA mixture leak down. The fact that mixtures' tensile strength ratios are more than 100% indicates that fibres don't cause the mixture to degrade when exposed to moisture. The use of tyre and carpet fibres makes SMA more durable. In comparison to SMA mixes including cellulose or mineral fibre, they observed no change in the amount of permanent deformation in SMA mixes incorporating waste fibres.

Kamaraj et al. (2004) carried out a lab research employing thick graded bituminous mix with cellulose fibre, stone dust, and lime stone as filler and established its compatibility as SMA mix by different tests. Natural rubber powder with 80/100 bitumen in SMA by wet process was also used.

Punith et al. (2004) conducted a comparison research between SMA and asphalt concrete mix using stabilising agent made from recovered polythene in the form of LDPE carry bags (3 mm size and 0.4%).The test findings showed that the use of recovered polythene as a stabiliser improved the mix qualities of both SMA and AC mixture, displaying greater resistance to rutting, resistance to moisture damage, rutting, creep, and ageing.

Reddy et al. (2004) utilised Crumb Rubber (CR) OBTAINED from scrap tyres with 80/100 penetration grade bitumen in SMA and found that it improved fatigue and permanent deformation properties, stronger resilience to moisture damage than standard mixtures.

Ibrahim M.asi (2005) performed many tests on both SMA and DGM, including the Marshall stability test, loss of Marshall stability, tensile strength, loss tensile strength, resilient modulus, fatigue life, and rutting resistance. In spite of DGM's strong tensile and compressive strengths, he came to the conclusion that SMA had superior durability, resilience, and rutting resistance than DGM did. SMA is therefore preferred in hot temperatures.

Muniandy and Huat (2006) utilised Cellulose Oil Palm Fibre (COPF) and discovered that when cellulose fibres were pre-blended with PG64-22 binder with fibre proportions of 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by weight of aggregates, fiber-modified binder demonstrated better rheological qualities. It demonstrated how the PG64-22 binder might be upgraded to PG70-22 grade. The fatigue performance of the SMA design mix was shown to be enhanced by the cellulose oil palm fibre (COPF). At a fibre content of around 0.6%, the fatigue life climbed to its maximum value, and the performance of the tensile stress and stiffness followed a similar pattern. With a 0.6% fibre content, the earliest strains of the mixture had the lowest levels.

Kumar et al. (2007) conducted a study comparing the use of two types of fibers in stone matrix asphalt (SMA) mixtures. They examined the performance of jute fiber, which was coated with a low viscosity binder, and compared it with an imported cellulose fiber from Germany. The SMA mixtures were prepared using 60/70 grade bitumen. The researchers determined that the optimal fiber percentage for the mixture was 0.3%. Interestingly, the jute fiber exhibited similar results to the imported cellulose fiber in terms of Marshall Stability Test, permanent deformation test, and fatigue life test. Moreover, the aging index of the mix containing jute fiber showed better results compared to the mix with the patented fiber.

Mustafa and Serdal (2007) Marshall test was done to evaluate the ideal binder content, and it produced positive results. Waste marble dust was employed, which was acquired from the shape of marble blocks and lime stone as filler.

Chiu and Lu (2007) used asphalt rubber (AR), created by combining tyre rubber (GTR) with (i) 30% coarse GTR with a maximum size of #20 sieve and (ii) 20% fine GTR with a maximum size of #30 sieve, as a binder for SMA, and discovered that the AR-SMA mixtures did not significantly differ from conventional SMA in terms of moisture susceptibility and showed better rutting resistance than that of conventional dense graded mixture.

Shaopeng Wu et al. (2007) employed basic oxygen slag as the aggregate, a modified version of PG76-22 as the binder, lime stone as filler, and chopped polyester fibre in SMA, and came to the conclusion that experimental SMA is superior than convectional SMA.

Xue et al. (2008) used polyester fibre of 6.35 mm in length obtained from recycled raw materials, PG76-22 binder in the SMA mix, and municipal solid waste incinerator (MSWI) fly ash as a partial replacement of fine aggregate or mineral filler and Basic Oxygen Furnace (BOF) slag as part of coarse aggregate with Marshall and super pave method of design and found it's suitability for use in the SMA mix.

C.S Bindu, Beena K.S. (2010) compared the properties of SMA with and without the use of shred waste plastic as a stabilising agent in stone matrix asphalt mixture. With variable percentages of bitumen (6-8%) and different percentages of plastic (6-12%) by weight of mix, the Marshall Test, compressive strength test, tensile strength test, and triaxial test were conducted.

Jony Hassanet.al.(2010) By contrasting SMA with SMA where lime stone and regular Portland cement were used as filler with varied contents (4–7%), it was possible to determine the impact of employing waste glass power as a mineral filler on the Marshall property of SMA. An ideal glass power content of 7% was discovered. Comparing SMA with lime stone and cement filler to SMA with glass power as filler, its stability rises by 13%, flow value falls by 39%, and density also falls.

The review of literature highlights the various research efforts conducted on SMA and Dense Graded Mix (DGM). Different materials, including fillers, binders, modifiers, fibers, and stabilizers, have been studied to improve the properties of SMA mixes. The present investigation aims to compare the properties of SMA and Bituminous Concrete (BC) mixes, using 60/70 penetration grade bitumen and fly ash as a filler. SISAL fiber, a non-conventional cellulose-containing material, has been used as a stabilizing additive in the mixes, contributing to waste management and exploring the use of unconventional materials in SMA.

5. PREPARATION AND TEST OF MIXES

The experimental mixes, both for Bituminous Concrete (BC) and Stone Matrix Asphalt (SMA), were prepared following the Marshall procedure outlined in ASTM D1559. The gradations of coarse aggregates, fine aggregates, and filler for BC and SMA were specified and presented in Table 3.1 and Table 3.2, respectively. Initially, a comparative study was conducted on BC using three different types of fillers: cement, fly ash, and stone dust. The Optimum Binder Content (OBC) for BC was determined through the Marshall Test, varying the binder content from 0% to 7%. Subsequently, the Optimum Binder Content (OBC) and Optimum Fiber Content (OFC) for both BC and SMA were determined using the Marshall Method. The binder content ranged from 0% to 7%, while the fiber content varied from 0.3% to 0.5%.

In the mixing process, the sisal fibers were cut into small pieces measuring 15-20 mm and directly added to the aggregate sample in different proportions. The mineral aggregates, along with the fibers and binders, were heated separately to the prescribed mixing temperature, with the aggregate temperature maintained 10°C higher than the binder temperature. The required amount of binder was added to the preheated aggregate-fiber mixture, and manual mixing was performed until the mixture achieved a uniform color and consistency. The mixing duration was controlled within 2-5 minutes. The mixture was then poured into preheated Marshall molds, and the samples were prepared by applying a compactive effort of 75 blows on each side.

Tests on Mixes: The various experiments performed on bituminous mixes with varying binder type and amounts, as well as fibre concentration in the mix, are shown below.

- Drain down test
- Marshall Test
- Indirect Tensile Strength Test
- Static Indirect Tensile Test
- Static Creep Test

6. CONCLUSIONS

The conclusions below are reached based on the findings and analysis of experimental research done on mixtures, including SMA and BC.

- All three types of fillers used in Bituminous Concrete (BC) meet the required specifications, making them suitable for use as fillers.
- While BC with cement filler provides the highest stability, the use of fly ash and stone dust as filler materials is also feasible, considering the cost-effectiveness. Additionally, incorporating fly ash helps in minimizing industrial waste.
- The Optimum Binder Content (OBC) for BC is determined as 5%, and the Optimum Fiber Content (OFC) is found to be 0.3%.
- The addition of fibers up to 0.3% in BC increases the Marshall Stability value. However, further fiber addition does not result in a significant increase in stability compared to Stone Matrix Asphalt (SMA).
- The inclusion of fibers in BC reduces the flow value compared to the mix without fibers, but adding 0.5% fiber leads to an increase in flow value.
- SMA without fibers has a binder requirement of 5.8%. By incorporating 0.3% sisal fiber into SMA, this value decreases to 5.2%. However, further fiber addition increases the binder requirement up to 6, leading to increased drain down.
- Adding 0.3% fiber to SMA significantly increases the Stability value, but further fiber addition causes a decrease in stability.
- Incorporating 0.3% fiber in SMA reduces the flow value, but adding more fiber increases the flow value.
- The main advantage of using fibers is the reduction in air voids in the mix and decreased drain down of the binder.
- SMA exhibits higher drain down compared to BC without fibers, but incorporating fibers at their OFC reduces the drain down of the binder.
- The Indirect Tensile Strength test indicates that SMA has higher tensile strength than BC.
- The Static Creep Test shows that adding fibers to both BC and SMA mixes reduces deformation. The recommended maximum permanent deformation according to MORTH is 0.5 mm, and SMA samples with fibers exhibit deformations around 0.45 mm, which is favorable.

Two types of bituminous mixes, Stone Matrix Asphalt (SMA) and Bituminous Concrete (BC), were prepared using 60/70 penetration grade bitumen as the binder. The mixes were enhanced by the addition of sisal fiber, a naturally available fiber, at varying concentrations ranging from 0% to 0.5%. The Optimum Binder Content (OBC) and Optimum Fiber Content (OFC) were determined using the Marshall Method of mix design. It was observed that incorporating 0.3% fiber in the mix resulted in improved properties.

The performance of the mixes was evaluated through various tests, including the Drain Down Test, Indirect Tensile Strength Test, and Static Creep Test. The results demonstrated that SMA with the inclusion of sisal fiber exhibited excellent performance, making it suitable for use in flexible pavement applications.

In summary, the use of sisal fiber in SMA improved the overall properties of the mix, as determined by the test results, such as reduced drain down, increased tensile strength, and minimized deformation under static load. These findings highlight the potential of utilizing SMA with sisal fiber in the construction of flexible pavements.

REFERENCES

1. ASTM D 1559 (1989), "Test Method for Resistance of Plastic Flow of Bituminous Mixtures Using Marshall Apparatus".
2. ASTM D 6931 (2007), "Indirect Tensile (IDT) Strength for Bituminous Mixtures".
3. Brown E.R. and Manglorkar H. (1993), "Evaluation of Laboratory Properties of SMA mixtures", *NCAT Report No. 93-5, Auburn University, Alabama.*
4. Brown E.R. and Mallick R.B. (1994), "Stone Matrix Asphalt Properties Related to Mixture Design", *NCAT Report 94-02.*
5. Bradley J. Putman and Serji N. Amirkhanian (2004), "Utilization of Waste Fibre in Stone Matrix Asphalt Mixtures", *Resources, Conservation and Recycling, Volume 42, Issue 3, pp 265-274.*
6. Bose S., Kamaraj C. and Nanda P.K. (2006), "Stone Mastic Asphalt (SMA) – A Long Life Pavement Surface", *International Seminar on Innovations in Construction and Maintenance of Flexible Pavements, Agra, 2-4 September, Technical Papers, Volume 1, pp 169-17.*
7. Chui-Te Chiu and Li-Cheng Lu (2007), "A Laboratory study on Stone Matrix Asphalt using Ground Tire Rubber", *Construction and Building Materials, Volume 21, Issue 5, pp 1027-1033.*
8. C.S Bindu, Beena K.S.(2010),"Waste Plastic as a Stabilizing additive in SMA", *International Journal of Engineering and Technology, Volume 2, Issue6, pp 379-387.*
9. Das A. and Chakroborty P. (2010), "Principles of Transportation Engineering", *Prentice Hall of India, New Delhi, pp 294-299.*
10. Das A., Deol, M. S. Ohri S. and Pandey B. B.(2004). "Evolution of non-standard bituminous mix – a study on Indian specification", *The International Journal of Pavement Engineering, Vol 5(1), pp. 39-46.*
11. H. Jony Hassan, Y. Jahad Israa (2010), "The Effect of Using Glass Power filler on Hot Asphalt Concrete Mixture Properties*", Engg and Technology journal, vol.29, Issue1, pp44-57.*
12. IS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P - I): Particle Size and Shape", *Bureau of Indian Standards, New Delhi.*
13. IS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P-III): Specific Gravity, Density, Voids, Absorption, Bulking", *Bureau of Indian Standards, New Delhi.*
14. IS: 2386 (1963), "Methods of Test for Aggregates for Concrete (P-IV): Mechanical Properties", *Bureau of Indian Standards, New Delhi.*
15. IS: 1203 (1978), "Methods for Testing Tar and Bituminous Materials: Determination of Penetration", *Bureau of Indian Standards, New Delhi.*
16. IS: 1205 (1978), "Methods for Testing Tar and Bituminous Materials: Determination of Softening Point", *Bureau of Indian Standards, New Delhi.*
17. IRC SP-79 (2008)," Specification for SMA".
18. Ibrahim M. Asi (2005), "Laboratory Comparison Study for the Use of Stone Matrix Asphalt in Hot Weather Climates", *Construction and Building Materials, Volume 20, Issue 10, pp 982-989.*
19. Karasahin Mustafa, Terzi Serdal (2007), "Evaluation of marbal waste dust in mixture of asphalt matrix", *Construction and Building Materials, Volume 21, Issue 5, pp 616-620*
20. Kamraj C., Kumar G., Sharma G., Jain P.K. and Venkanna Babu P. (2004), "Laboratory Studies on the Behaviour of Stone Matrix Asphalt vis-à-vis Dense Graded Bituminous Mixes using Natural Rubber Powder (Wet Process)", *Highway Research Bulletin, No 71, IRC, New Delhi, pp39-60.*

21. Khanna S.K. and Justo C.E.G. (2001), "Highway Engineering", *Nem Chand andBros, Roorkee, pp315-321.*

22. Kumar Pawan, Chandra Satish and Bose Sunil (2007), 'Laboratory Investigations on SMA mixes with Different Additives', *International Journal of Pavement Engineering, Volume 8, Issue1, pp 11-18.*

23. Mogawer W.S. and Stuart K.D. (1996), "Effect of Mineral Fillers on Properties of Stone Matrix Asphalt Mixtures", *TRR 1530, National Research Council, TRB, USA, pp 86 -94.*

24. Muniandy Ratnasamy and Huat Bujang B.K. (2006), "Laboratory Diameteral Fatigue Performance of Stone Matrix Asphalt with Cellulose Oil Palm Fibre", *American Journal of Applied Sciences 3 (9): 2005-2010.*

25. Punith V.S., Sridhar R., Bose S., Kumar K. Kantha and Veeraragavan A. (2004), "Comparative Studies on the Behaviour of Stone Matrix Asphalt and Asphaltic Concrete Mixtures utilizing Reclaimed Polyethylene", *Highway Research Bulletin, No 71, IRC, New Delhi, pp 61-76.*

26. Reddy K.S., Palit S.K. and Pandey B.B. (2004), "Laboratory Evaluation of Crumb Rubber Modified Asphalt Mixes", *Journal of Materials in Civil Engineering, ASCE, pp 45-53.*

27. Suchismita Arpita (2009)," A Study of Effects of Binder Quality and Natural Fiber on the Properties of Stone Matrix Asphalt Mixtures", *M.tech Thesis, National Institute of Technology, Rourkela.*

28. Yongjie Xue, Haobo Hou, Shujing Zhu and Jin Zha (2009), "Utilization of Municipal Solid Waste Incineration Ash in Stone Mastic Asphalt Mixture: Pavement Performance and Environmental Impact", *Construction and Building Materials, Vol. 23, Issue 2, pp 989-996*

29. http://www.pavementinterective.org/article/hma-types/ J.V.Merighi, R.M.Fortes, "The Study of permanent deformation using static creep test".