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Utilization of Fiber Modified Stone Matrix Asphalt (SMA) Mixes in Egypt

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استخدام الخلطات الاسفلتية الحجرية المحسنة بالألياف في مصر

تعد الخلطات الاسفلتية الحجرية احد انواع الخلطات الاسفلتية ذات التدرج الناقص و التي تعتمد بشكل كبير على ارتكاز حبيبات الركام على بعضها كمصدر اساسي لتفوقها مما يجعلها من انسب انواع الخلطات الاسفلتية مقاومة لظاهرة التخدد. الخلطات الاسفلتية الحجرية تتكون بشكل رئيسي من نسبة كبيرة من الركام كبير الحجم (الخشن) و محتوى عالى من الاسفلت و نسبة عالية من المواد الناعمة بالاضافة الى استخدام مجموعة من الاضافات لمقاومة ظاهرة استنزاف او تسرب البيتومين اثناء عملية نقل الخلطة او فرشها على الطريق. وفقا للمواصفات القياسية للخاطات الحجرية فان الالياف السليلوزية او الالياف المعدنية تعد من انسب انواع الاضافات لاستخدامها في الخلطة و لكن نتيجة عدم توافر هذه الانواع من الالياف في بعض الدول فقد قامت العديد من الدراسات لمحاولة ايجاد بدائل محلية صالحة لاستخدامها في الخلطات الحجرية.

الهدف الاساسي من الرسالة هو دراسة سلوك الخلطات الحجرية في مصر باستخدام نوع من الالياف محلية الصنع الا وهي الالياف الزجاجية نظرا لانتشارها بكثرة في مصر بالاضافة الى تحديد محتوى الالياف الزجاجية الامثل لاستخدامه في الخلطة طبقا لتدرجاتها.

تم اختيار تدرجين من تدرجات الخلطات الحجرية في هذه الدراسة و هما التدرجات ذات الحد الاسمي الاقصى 12.50 مم و ذات الحد الاسمي الاقصى 19.00 مم لاختبارهما عند أربعة نسب مختلفة من الالياف الزجاجية الا و هي 0.00% و 0.30% و 0.50% و 0.70% من اجمالى وزن الخلطة و قد تم اختبار العينات في مجموعة من اختبارات الاداء و هي اختبار مارشال للثبات و اختبار الفقد في الثبات و اختبار الشد غير المباشر و اختبار نضوح الاسفلت.

اظهرت النتائج و بشكل عام تفوق العينات ذات الحد الاسمي الاقصى 19.00 مم في كافة الاختبارات كما اظهرت انه بالنسبة للحد الاسمي الاقصي 12.50 مم فقد وجد ان افضل النتائج تقريبا في جميع الاختبارات كانت مع العينات ذات نسبة الياف زجاجية 0.70% في حين ان افضل النتائج بالنسبة للعينات للخلطات ذات الحد الاسمي الاقصى 19.00 مم كانت للعينات ذات نسبة الياف 0.50%.

Abstract:

Stone matrix asphalt (SMA) is considered as a gap graded hot mix asphalt (HMA) which gains its main strength from stone on stone contact the thing that makes it durable and rut resistant mix. SMA consists of high proportion of coarse aggregate, significantly high proportion of fillers, high binder content, and stabilizing additives to prevent draindown that might occur during transporting or placing mixture. According to SMA standards, cellulose and mineral fibers were found to be the most suitable fibers to be used with SMA, although due to lack of those specific types of fibers in some countries, plenty of studies were done to find replacements using local fibers.

The main scope of this thesis is to study the behavior of SMA mixtures using local type of fibers which is chosen to be fiberglass as it is one of the most common used fibers in Egypt as well as determine the optimum fiber content that should be used in SMA according to its gradation.

Two different SMA gradations were tested in this thesis, nominal maximum aggregate size (NMAS) 12.50 mm and NMAS 19.00 mm at four different fiber contents for each gradation 0.00 %, 0.30 %, 0.50 %, and 0.70 % of total weight of the mix. SMA samples were tested through series of performance tests selected to be Marshall stability test, moisture susceptibility test, indirect tensile strength test (ITS), and draindown test.

Results showed that for NMAS 12.50 mm, increasing fiber content from 0.00 % to 0.70 % enhanced almost all characteristics of the mix, as the results of the mix with 0.70 % fiber content showed a significant improvement at almost all tests comparing to other samples, on the other hand for NMAS 19.00 mm, mixtures with fiber content 0.50 % showed a great improvement over all other samples at the same gradation, and overall NMAS 19.00 mm showed to produce asphalt mixtures with better mechanical properties than NMAS 12.50 mm at all tests.

Key Words: Stone matrix asphalt, hot mix asphalt, nominal maximum aggregate size, fiberglass, Marshall, indirect tensile strength.

1. INTRODUCTION

Nowadays, the field of developing asphalt mixtures has been improved so much rapidly and by all means, a lot of studies were done and theses were discussed all over the world trying to improve the mechanical properties of asphalt mixture in order to enhance some of its characteristics by attempting to change gradations or by using additives to be added to the mix but it is a must to try to develop asphalt mixture to face all kinds of pavement distresses which increase the cost of road maintenance and affect the performance of the asphalt which may lead to different kinds of accidents.

One of the main steps to be taken into consideration in the scope of developing asphalt mixes is additives, many studies and researches discussed the effect of adding extra additives to conventional asphalt mix and test its performance and the improvement that might happen in its mechanical properties. (Cloutier & Sobolev, 2016), tried to test behavior of asphalt mix according to moisture susceptibility, workability, and aging resistance while using some materials produced through coal combustion process like fly ashes and it was noticed that cracking resistance improved significantly after using the ashes.

(Nguyen & Le, 2018) in Vietnam tried to replace coarse aggregate used in the asphalt mixtures with steel slag at four different percentages 0.00%, 25.00%, 50.00%, and 75.00% and tested the samples through Marshall stability, indirect tensile strength (ITS), and modulus of resilience and declared that replacing aggregate with slag significantly improves mixture's properties.

Rutting is considered one of the most harmful distress that affects pavement, rutting by definition is a groove formed at the pavement due to material loss or due to the shear forces that affect pavement from the movement of heavy vehicles over it, rutting can be so dangerous as it decreases quality and efficiency of the road as long as it contributes to accidents that might take place due to the assembling of rain water in those grooves which affects stability of vehicles on the road which is called hydroplaning accidents (Vargas-nordcbeck, 2016), (Holtzheimer & Mayberg, 2011). SMA was one of the asphalt mixtures developed in the same scope in order to face all shapes of permanent deformations specially rutting.

2. LITTERATURE REVIEW

Stone matrix asphalt is a hot mix asphalt that is considered as a gap graded mix and contains high percentage of coarse aggregate, high percentage of fillers, suitable content of fibers, almost total absence of fine aggregates, and a high percentage of asphalt to connect the aggregate particles together. The main reason of fibers in the mix is to reduce the drain down that might occur as a result of the high binder content during transportation or placing the mix.

Stone matrix mixtures were firstly developed at Kiel city in Germany at 1968 and was tested to be used in some local areas there, then it was transferred into the United States in a huge study that declared the effectiveness of this new mixture and there was a huge project to use SMA mixtures in 20 different states and to study the behavior of the mix and how effective it is as a durable rut resistant surface wearing layer (Waanders & Els, 1995).

Beside SMA, some researchers tried different solutions to face rutting to avoid using traditional treatment techniques such as overlay layers or road reconstruction as these solutions are expensive. (Fan, 2010), tried to use a mix concrete asphalt pavement as a try to decrease rutting values, in his study two cases were put under test, monolayer concrete asphalt and the double deck concrete asphalt and the result of the study was that double deck layer showed a better response to rutting than the monolayer but overall the whole asphalt concrete layers was not significantly effective against rutting.

(Morea, Zerbino, & Agnusdei, 2013) tried to control rutting in asphalt mixtures by studying the direct relationship between low shear viscosity (LSV) and rutting -which was determined using wheel track test- and the conclusion was that rutting resistance for asphalt mixtures drops hardly when LSV drops under 500 Pa.s for original binder and 2000 Pa.s for aging binder, thus with controlling LSV values, rutting depth can be controlled.

According to AASHTO specifications which concerns SMA mixtures, cellulose fibers and mineral fibers are the most suitable types of additives to be used in SMA due to their effectiveness in reducing the draindown values, but due to lack of those specific types of fibers in some countries, researches there started to test local types of fibers to be used in SMA mixture or even using other additives than fibers, and it was discovered that some of the used fibers did not only reduce draindown values, but also it enhanced some of other mechanical properties of the mix depending on fiber content used.

(Ferreira Da Costa, Lucena, Lucena, & Grangeiro De Barros, 2020) in Brazil tried to use banana fibers as a replacement for cellulose or mineral fibers by changing fiber length and using the same fiber content and compare results, 5, 10, 15, 20 mm fiber length were set to be tested with fiber content 0.30%, and the conclusion was that samples with fiber length 15 mm and 20 mm showed better performance than other samples at conducted tests which were indirect tensile strength, flow number, and dynamic modulus.

(Do Vale, Casagrande, & Soares, 2014) tried to study the difference between the behavior of SMA mixtures using cellulose fibers and coconut fibers using moisture susceptibility test, indirect tensile, and drain down, and the results showed that cellulose fibers gave better response than coconut fibers at almost all tests, even though coconut fibers showed a great value against draindown which it a good point proves it might not be same quality as cellulose but it is usable in the mixtures.

(Kiran Kumar & Ravitheja, 2019) in India tested and compared the results between using three different types of fibers coir fibers, sisal fibers, and banana fibers. The study was to determine the change of SMA properties according to the type of fiber and to try to determine the optimum fiber content to be used in the mix which was illustrated to be around 0.30% as it was discovered that the mix collapsed and lost its stiffness and strength after increasing fiber content over 0.30%. The conclusion was that coir fiber showed a better value to be used in the mix while sisal and banana fibers were almost the same and had almost the same results at all set tests.

(Muniandy & Huat, 2006) in Malaysia tested oil palm fibers as a replacement to cellulose fibers and tried to determine optimum oil fiber content to be used by assembling samples with five different fiber content 0.20%, 0.40%, 0.60%, 0.80%, and 1.00% and testing samples through fatigue circle test, stiffness, and ITS test. The final results for all samples showed that optimum oil palm fiber content for SMA is 0.60%.

(Karunakar, Sravana, Goud, & Sowjanya, 2018) tried in his study to know the effect of replacing glass fiber with carbon fiber in SMA and to determine optimum fiber content to be used in the mixture. The conclusion of the thesis was that the optimum fiber is 0.30% of total weight of the blend and the optimum bitumen content was about 6.55% and stability dropped almost 12.00% with glass fiber lower than carbon fiber.

(Gong et al., 2019) tested using pre-coated rubber aggregate in SMA and testing its mechanical properties to see if there is any improvement to notice. The study eventually showed that samples with pre-coated rubber had a better performance in terms of ITS values and strength loss, so it is a promising solution to be tested further in the future.

Fiberglass is not only used in asphalt mixtures, but also is being used in so many studies as an additive and in this part some applications of fiberglass from previous studies will be discussed.

Depending on the results of a study made in the United States by (Graydon, Beatty, Paul, Us, & Hauck, 2006), researchers here tried to add fiberglass to the binder in order to improve some of its chemical properties, the study illustrated that fiberglass tested with a binder with PH less than 3.50 to enhance the binder with catalysts which give a better performance in generating fiberglass products. The conclusion was that using fiberglass binder was found to be useful as it reduces producing difficulties and increases both recovery and rigidity.

Advantages of SMA mixtures can be listed to be

- SMA mixtures give a durable mix with hard surface texture.
- SMA is very effective against permanent deformation distresses like rutting.
- Being a gap graded mix gives SMA advantage to be used to reduce noise.

Disadvantages of SMA can be listed to be

- SMA mixtures are more expensive than dense mix due to the existence of fibers inside it which requires some expenses, but this should not be a problem while using local fiber which is cheap and available.
- SMA contains high binder content 6.00% to 7.00% which is also more expensive than conventional mix.
- Apart from resistance to permanent deformation, SMA mixtures seems to give a lower performance than normal dense mix in terms of stability or loss of stability or ITS.

3. MATERIALS

One of the keystones for any asphalt mixture is materials used in the mix, for SMA materials used in the mix are coarse aggregate, fine aggregate, fillers, binder, and stabilizing additives.

Aggregate and fillers used in this study is considered as dolomitic limestone as it is common to be used in asphalt in Egypt, and it was brought by local contractor.

Binder used in the study is bitumen (60/70) as it is the popular bitumen used in Egypt and was brought from a refinery near Suez city, Egypt.

Additives selected to be fibers and the type of fibers selected was fiberglass as it is commonly used in concrete mixtures in Egypt and it was brought from a company called Sika.

4. TESTING STRATEGY

First step of the study was to test validation of material used according to ECP limits through some validation tests. Aggregate was tested through Los Angeles abrasion test, flakiness and elongation test, absorption test, and stripping test.

Binder was tested through penetration test, softening point test, and rotational viscosity test. Both aggregate and binder showed accepted values at all tests according to ECP.

Then, set of samples were prepared according to the selected gradations which were NMAS 12.50 mm and 19.00 mm following AASHTO recommendations and Marshall mix design was used to determine optimum asphalt content for each gradation. For each gradation four different fiber contents were tested which were 0.00%, 0.30%, 0.50%, and 0.70% and final SMA mixtures were tested through four performance tests which were Marshall stability test, loss of stability test, ITS test, and draindown test. All the results were noticed, and final conclusion was discussed to declare the optimum fiberglass content to be used in the mix for each gradation.

5. RESULTS

In this section all tests results will be stated. Table 1 shows aggregate validation tests results. Table 2 shows binder validation tests results.

Table1: Aggregate validation tests results

Test	*PIN 1*	*PIN 2*	*Limitations*
L.A. abrasion (%)	*26.40*	*26.50*	*40*
F & E (%)	*6.70*	*6.40*	*10*
Absorption (%)	*2.70*	*2.60*	*5*
Stripping (%)	*>95*	*>95*	*-*

Table 2: Binder validation tests results

Test	*Binder*	*Limitations*	
Penetration	*64*	*60*	*70*
Rotational viscosity	*430*	*320*	*-*
Softening point	*49*	*45*	*55*

Tables 3&4 show blend gradations for NMAS 12.50 mm and 19.00 mm respectively, also figures 1&2 show blend gradation according to upper and lower limits stated by AASHTO.

Table 3: Blend gradation for NMAS 12.50 mm

AASHTO SMA gradation specifications for NMAS 12.50 mm				
Sieve Size (Inch)	***Sieve Size (mm)***	***% Passing***		***%Passing***
		Lower	***Upper***	***Blend***
#1	***25.40***	***100.0***	***100.0***	***100.0***
#3/4	***19.00***	***100.0***	***100.0***	***99.6***
#1/2	***12.50***	***90.0***	***100.0***	***92.9***
#3/8	***9.50***	***50.0***	***80.0***	***79.2***
#4	***4.75***	***20.0***	***35.0***	***23.0***
#8	***2.36***	***16.0***	***24.0***	***19.5***
#30	***0.60***	***-***	***-***	***-***
#50	***0.30***	***-***	***-***	***-***
#80	***0.15***	***-***	***-***	***-***
#100	***0.15***	***-***	***-***	***-***
#200	***0.12***	***8.0***	***11.0***	***9.5***

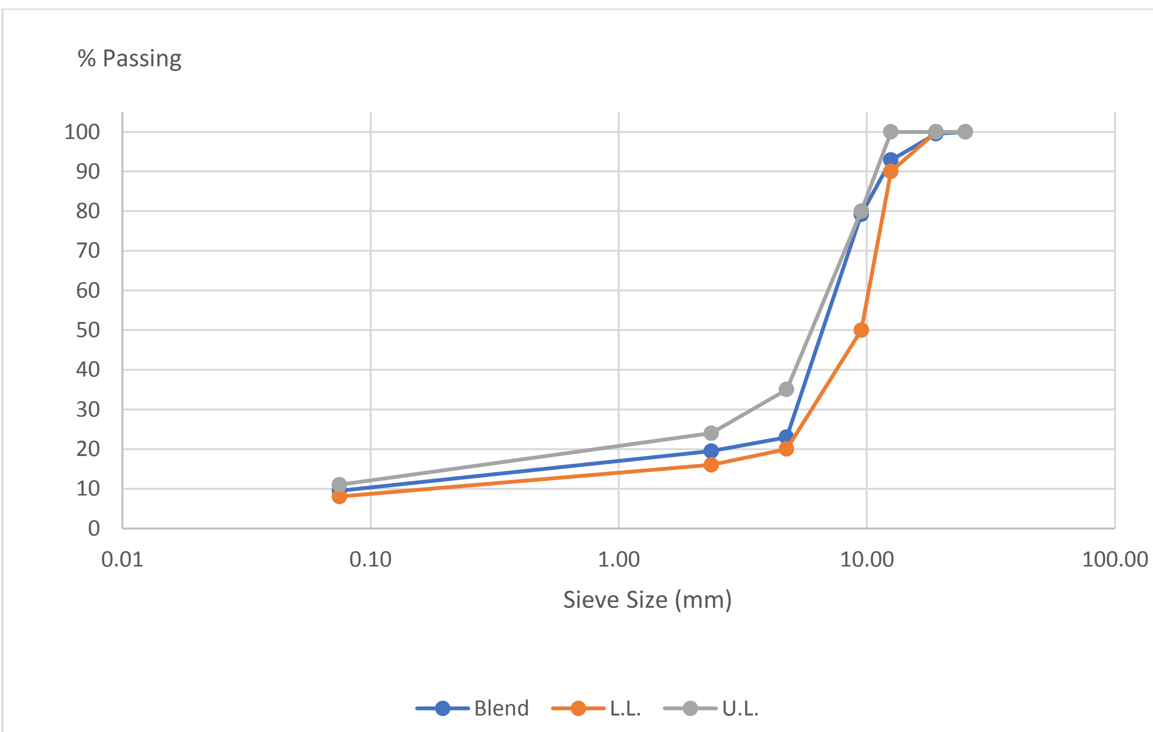

Figure 1: Blend gradation for NMAS 12.50 mm

Table 4: Blend gradation for NMAS 19.00 mm

Gradation of Coarse Aggregate				
Sieve Size (Inch)	Sieve Size (mm)	% Passing		%Passing
		Lower	Upper	Blend
#1	25.40	100.0	100.0	100.0
#3/4	19.00	90.0	100.0	97.7
#1/2	12.50	50.0	88.0	67.5
#3/8	9.50	25.0	60.0	52.4
#4	4.75	20.0	28.0	22.9
#8	2.36	16.0	24.0	19.5
#30	0.60	-	-	-
#50	0.30	-	-	-
#80	0.15	-	-	-
#100	0.15	-	-	-
#200	0.12	8.0	11.0	9.5

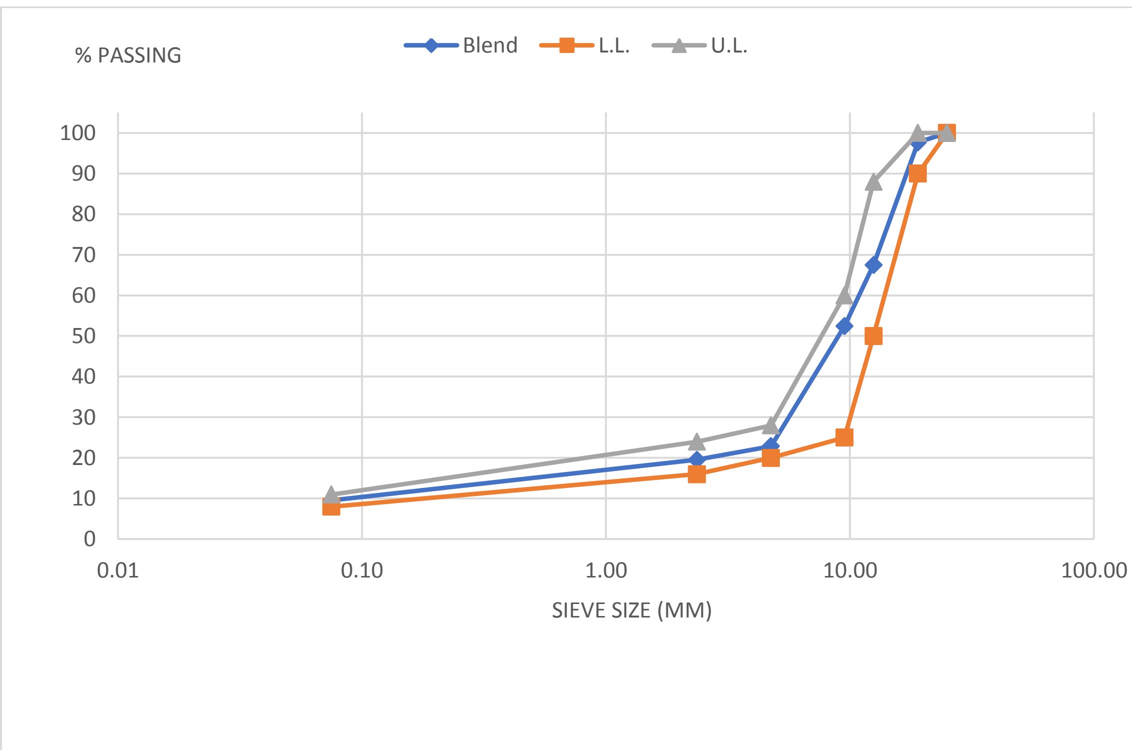

Figure 2: Blend gradation for NMAS 19.00 mm

Tables 5 & 6 show Marshall mix design results for both NMASs.

Table 5: Marshall mix design results for NMAS 12.50 mm

Properties	***Marshall mix design result***
Optimum bitumen content (%)	***6.55%***
Mix specific gravity (g/cm^3)	***2.59***
Air void (%)	***4.00%***
Voids in mineral aggregate (%)	***17.75%***
Marshall stability (Kg)	***1020***
Flow (mm)	***2.75***
MQ (Kg/mm)	***370.90***

Table 6: Marshall mix design results for NMAS 19.00 mm

Properties	***Marshall mix design result***
Optimum bitumen content (%)	***6.25%***
Mix specific gravity (g/cm^3)	***2.61***
Air void (%)	***4.50 %***
Voids in mineral aggregate (%)	***18.15%***
Marshall stability (Kg)	***1150***
Flow (mm)	***3.75***
MQ (Kg/mm)	***306.66***

Figure 3 shows Marshall stability results for both gradations. Figure 5 shows loss of stability test results. Figure 6 shows ITS test results. Figure 7 shows draindown test results.

Tables 7&8 show draindown calculations and results for NMAS 12.50 mm and 19.00mm respectively. All figures contain the test results relatively with fiber content used in the sample.

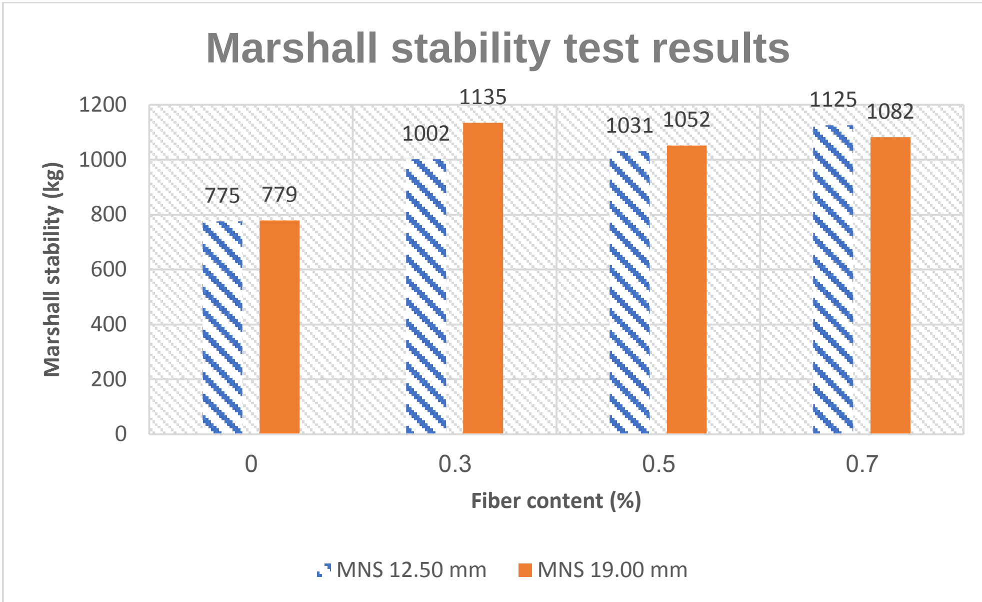

Figure 3: Marshall stability test results

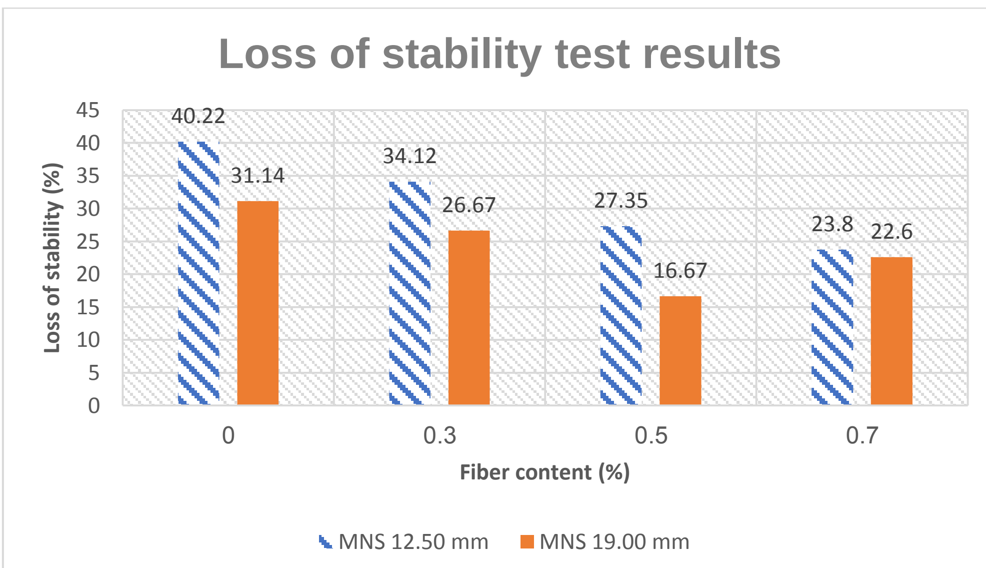

Figure 4: Loss of stability test results

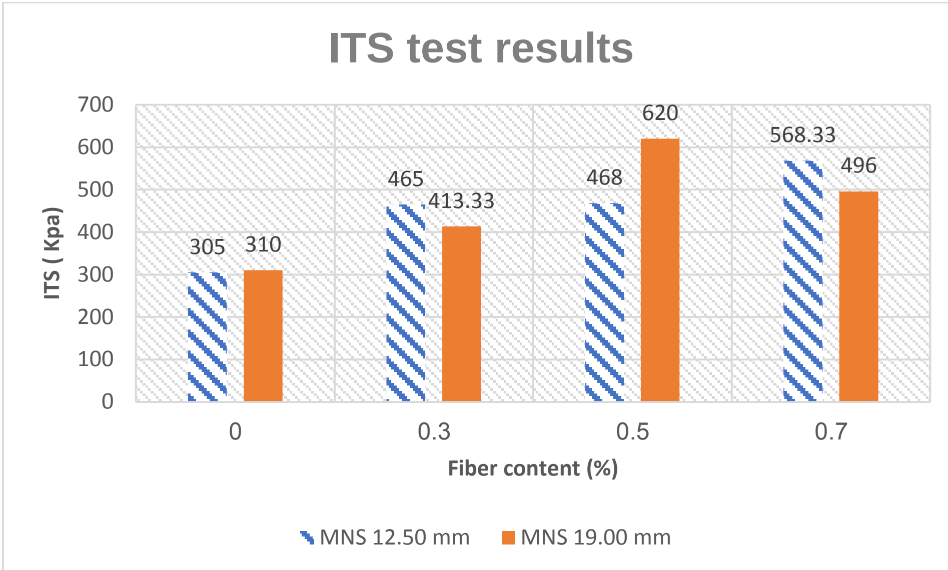

Figure 5: ITS test results

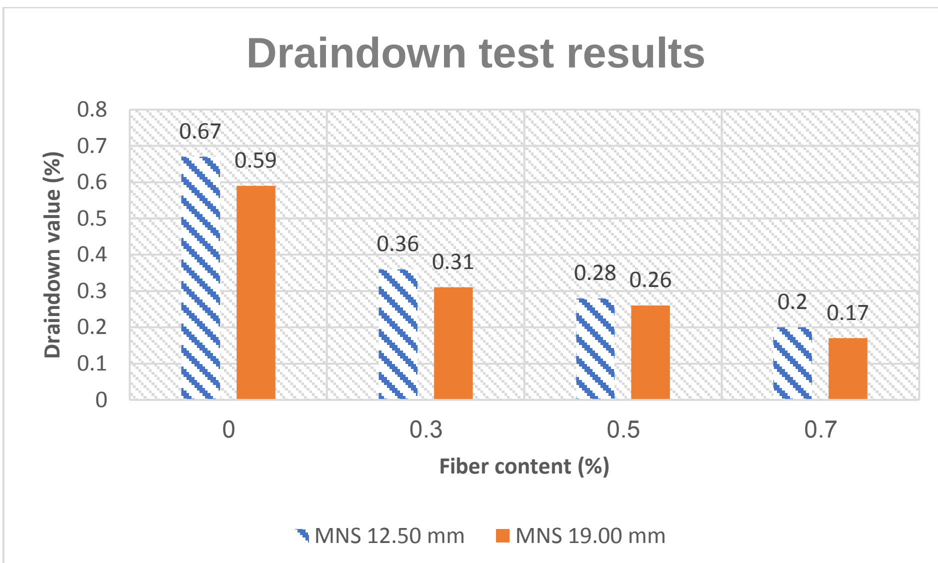

Figure 6: Draindown test results

able 7: Draindown results for NMAS 12.50 mm

Fiber Content (%)	***Container original Weight (gm)***	***Original Blend weight (gm)***	***Container with blend after heating weight (gm)***	***Draindown value (%)***
0.00	***830***	***1220.15***	***838.17***	***0.67***
0.30	***830***	***1219.38***	***834.39***	***0.36***
0.50	***830***	***1220.67***	***833.42***	***0.28***
0.70	***830***	***1218.53***	***832.44***	***0.20***

Table 8: Draindown results for NMAS 19.00 mm

Fiber Content (%)	***Container original Weight (gm)***	***Original Blend weight (gm)***	***Container with blend after heating weight (gm)***	***Draindown value (%)***
0.00	***830***	***1219.16***	***837.19***	***0.59***
0.30	***830***	***1219.78***	***833.78***	***0.31***
0.50	***830***	***1221.38***	***833.18***	***0.26***
0.70	***830***	***1220.65***	***832.08***	***0.17***

6. CONCLUSION

The Main conclusions of the thesis can be stated in following points

- SMA mixtures with MNS 19.00 mm were better than mixtures with 12.50 mm almost at all performance tests.
- Changing fiber content in SMA mixture can highly affect the performance of the mix which was proved according to the results.
- For MNS 12.50 mm it was also noticed that loss of stability value decreases with the increase on fiber content, and indirect tensile strength value increases as the mix with fiber content 0.70 % scored the best results for Marshall stability, loss of stability, and indirect tensile strength tests.
- For MNS 19.00 mm, SMA mixture with fiber content 0.50 % showed a great performance in loss of stability and in direct tensile strength tests according to all other mixtures with different fiber content.

- For both gradations and as expected, the value of draindown kept decreasing with the increase of fiber content but since AASHTO recommends maximum draindown value to be 0.30 % so any mixture with lower draindown value is accepted.
- According to previous discussion, in my opinion for MNS 12.50 mm, SMA mix with fiber content 0.70 % is the best to be used with fiber glass.
- For 19.00 mm, SMA mix with fiber content 0.50 % is the best to be used with fiber glass.

7. REFRENCES

AASHTO (2011) A Policy on Geometric Design of Highways and Streets. The American Association of State Highway and Transportation Officials, AASHTO Green Book, Washington DC.

Cloutier, C., & Sobolev, K. (2016). The effective use of coal combustion products (CCPs) in asphalt pavements. (May).

Do Vale, A. C., Casagrande, M. D. T., & Soares, J. B. (2014). Behavior of natural fiber in stone matrix asphalt mixtures using two design methods. Journal of Materials in Civil Engineering, 26(3), 457–465. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000815

Fan, T. J. (2010). Rut resistance behavior of pavement structures combined by the different asphalt mixtures. 2010 International Conference on E-Product E-Service and E-Entertainment, ICEEE2010. https://doi.org/10.1109/ICEEE.2010.5660381

Ferreira Da Costa, L., Lucena, L. C. D. F. L., Lucena, A. E. D. F. L., & Grangeiro De Barros, A. (2020). Use of Banana Fibers in SMA Mixtures. Journal of Materials in Civil Engineering, 32(1). https://doi.org/10.1061/(ASCE)MT.1943-5533.0002994

Gong, F., Guo, S., Chen, S., You, Z., Liu, Y., & Dai, Q. (2019). Strength and durability of dry-processed stone matrix asphalt containing cement pre-coated scrap tire rubber particles. Construction and Building Materials, 214, 475–483. https://doi.org/10.1016/j.conbuildmat.2019.04.151

Graydon, I., Beatty, E., Paul, S., Us, M. N., & Hauck, J. A. (2006). (12) United States Patent. 1(12).

Holtzheimer, P. E., & Mayberg, H. S. (2011). Stuck in a rut: Rethinking depression and its treatment. Trends in Neurosciences, 34(1), 1–9. https://doi.org/10.1016/j.tins.2010.10.004

Karunakar, K., Sravana, P., Goud, K. G., & Sowjanya, T. (2018). Properties of Stone Matrix Asphalt Using Carbon Fiber and Glass Fiber. International Journal of Engineering Sciences Invention (IJESI), 7(6), 45–52.

Kiran Kumar, N. L. N., & Ravitheja, A. (2019). Characteristics of stone matrix asphalt by using natural fibers as additives. Materials Today: Proceedings, 19, 397–402. https://doi.org/10.1016/j.matpr.2019.07.624

Morea, F., Zerbino, R., & Agnusdei, J. (2013). Improvements on asphalt mixtures rutting performance characterization by the use of low shear viscosity. Materials and Structures/Materiaux et Constructions, 46(1–2), 267–276. https://doi.org/10.1617/s11527-012-9900-8

Muniandy, R., & Huat, B. B. K. (2006). Laboratory Diameteral Fatigue Performance of Stone Matrix Asphalt with Cellulose Oil Palm Fiber. American Journal of Applied Sciences, 3(9), 2005–2010. https://doi.org/10.3844/ajassp.2006.2005.2010

Nguyen, M. T., & Le, A. T. (2018). Performance of Hot Mix Asphalt Concrete When using Electric-Arc Furnace Slag as Natural Coarse Aggregate. Proceedings 2018 4th International Conference on Green Technology and Sustainable Development, GTSD 2018, 831–834. https://doi.org/10.1109/GTSD.2018.8595535

Vargas-nordcbeck, A. (2016). The Roles of Accelerated Pavement Testing in Pavement Sustainability. In The Roles of Accelerated Pavement Testing in Pavement Sustainability. https://doi.org/10.1007/978-3-319-42797-3

Waanders, G., & Els, H. (1995). Splittmastixasphalt und Dränasphalt in den Niederlanden. Erfahrungen und Untersuchungen in der Provinz Overijsel. Asphalt, 95(4), 8–17.