Volumetric Optimization and Moisture Sensitivity Analysis of Crumb Modified Stone Mastic Asphalt

Hasnain Gardezi and Arshad Hussain

***Abstract*—Pre-mature failure of hot mix asphalt pavements in Pakistan is generally due to intense loadings owing to which frequent maintenance is required. To prevent pre-mature failure and make pavements economically efficient and effective, several alternatives should be designed. In this study, pavement made of Stone Matrix Asphalt (SMA-25) is proposed as an alternative to increase the service life and minimize the damages in terms moisture sensitivity. The study includes the use of Crumb rubber and Munjin fiber as main additives in Bitumen. Study is composed of two parts in first part change in behavior/properties of bitumen was studied by addition of crumb rubber @ 2%, 4%, 6%, 8%, 10% and 12%. In second part, volumetric properties and performance behavior of SMA-25 were studied. It was found that mix showed good behavior at 5.8% bitumen content and 4.8% rubber content. It was observed that volumetric behavior of Crumb modified SMA was totally reversed to that of Conventional SMA. Crumb modified SMA also showed good behavior against moisture sensitivity at optimum rubber content.**

***Index Terms*—Stabilizing agent, stone matrix asphalt, hot mix asphalt, modified asphalt pavement, Munjin fibers, CRUMB rubber, moisture sensitivity.**

I. INTRODUCTION

Generally, there are two types of pavements in road construction, which are the flexible pavement and the rigid pavement. Flexible pavements are approximately 90% of Pakistan's road network. The flexible pavement is normally constructed with hot mix asphalt. HMA pavements normally require frequent maintenance and rehabilitation due to damages caused by excessive traffic loadings. Along with that in heavy rain fall areas, the life of HMA pavement is quite less as it deteriorates. Therefore, it is needed to have an alternative pavement which can reduce damages and maintenance cost of pavement and prolong the service life. All HMA pavements can't be converted to rigid pavement because it is too much costly. So, among several alternatives, there is one better alternative of stone matrix asphalt commonly known as SMA. Stone matrix asphalt (SMA) is a stone-on-stone like skeletal structure of gap graded aggregate, bonded together by matrix, Having higher binder content, filler and fiber 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[1] . High percentage of binder content is important to ensure the durability and laying characteristics of SMA. Because of the formation of stone-to-stone aggregate skeleton, SMA can provide an extremely high rut resistant and durable mixture as compared with dense-graded asphalt mixture. SMA has high percentage of course aggregate which is about 70-80% as compared to HMA. In this study, along with Fiber in SMA Crumb Rubber was also incorporated at different percentages.

Waste rubber tires are those which have been used for a long term and have damaged sides, damaged corrugations, have bulges and can't be retreaded due to excessive usage. Now a day's number of vehicles is rising day by day, every day you move out of your house you will find a new type of vehicle on the road. Talking of Pakistan which is under developing country, total number of registered vehicles according to survey conducted by Global Health Organization (GHO) in 2011 is 9080,437**.** So, with this ongoing rise in use of motor vehicles, hundreds and millions of tires are discarded each year worldwide. The worldwide production of waste tires is about 5.0×10^6 tons per year, which is 2% of the total annual solid waste. The European Union produces more than 2.5×10^6 tons of waste tires per year [2]. Many of these discarded tires are added to existing tire dumps or landfills, and little number are gathered for recycling. This huge amount of scrap tires, rather in dumps or in recycling facilities, pose serious fire protection challenges to fire departments. Tires burn with a high amount of per-pound heat output than most of the coal, and the high heat production of tire rubber makes extinguishment very difficult [3].When the tires catch fire a large amount of flammable oil is yielded, this oil is not only flammable but also environment contaminating. Crumb rubber was used in stone matrix asphalt, as waste rubber tire is produced in a large amount every year, and it is too difficult to dump such big amount. In the study truck tire rubber containing 70% natural rubber was used in ground form. Than the ground rubber was blended in 80-100 bitumen. Mix was tested against stability, resilient modulus, dynamic creep and tensile strength ratio. Along with the ground tire 0.3% newly developed cellulose oil palm fiber was also used to prevent the drain down of mix. It was found that the SMA mix modified with rubber has much better performance as compare to unmodified [4]. In another study Fatigue life of SMA was investigated by addition of crumb rubber; he added 6%, 8%, 10% and 12% crumb by weight of bitumen. The study was aimed to check the effect of crumb rubber on stiffness and fatigue properties of SMA at optimum binder content. The tests he conducted are, dynamic stiffness (indirect tensile test), dynamic creep and fatigue test (indirect tensile fatigue test) [5]. Another study conducted on "Rubber modified binders as an alternative to Cellulose fiber – SBS polymers in Stone Matrix Asphalt." The study aimed to use two different binders modified with two elastomeric polymers, SBS and Crumb Rubber, for both the binder's aggregate gradation

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was same SMA11 was used in the study [6]. To determine the optimum bitumen content marshal test was conducted. And whence the binder content was determined other performance tests was conducted (Water sensitivity, binder drainage and wheel tracker test).

II. Gradation for SMA

Selection of gradation for SMA is an issue of concern; it should be selected such that it is economical and best suited to conditions. Effect of aggregate gradation of SMA was evaluated on rutting, stiffness and fatigue performance of stone matrix asphalt with different nominal maximum aggregate size. Four SMA mixes having nominal maximum size of 4.75, 9.5, 12 and 19mm were analyzed [7]. Another study was objected to investigate the influence of maximum size of aggregates on permanent deformation characteristics of Stone matrix asphalt. Four nominal maximum sizes of aggregates, 9.5mm, 12mm, 19mm and 25.4mm were used. All these four mixes were investigated for wheel tracker test at 25, 40 and 60 ℃. it was revealed that rutting in stone matrix asphalt for any number of loading passes is a function of maximum size of aggregates and testing temperature. Further it was found that rutting increased with increase in temperature and decreased with a decrease in aggregate size [8]. In this study SMA-25 is used. Shown in Table I.

Aggregates were obtained from Margalla quarry site and were tested against mechanical properties shown in Table II.

TABLE I: SMA-25

Sr. No	Sieve Size (mm)	% Passing	% Taken	Taken (gm)
1	25	100	0	0
2	19.4	90-100	93	84
3	12.5	50-88	60	396
4	9.5	25-60	40	240
5	4.75	20-28	25	180
6	2.36	16-24	20	60
7	0.075	8-11	10	120
8	Pan	10	10	120

TABLE II: Mechanical Properties of Aggregates

Sr. No	Aggregate Test	Result
1	Aggregate impact value	14.56% < 35%
2	L.A Test	23.47% < 30%
3	Sand Equivalent Test	41% (26-60%)
4	Soundness Test	21.86% > 10%
5	Flakiness Index	21.85% < 40%
6	Elongation Test	7.05% < 10%
7	Specific Gravity (Bulk, Apparent)	2.4, 2.48
8	Water Absorption	1.4% < 2%

III. Crumb Rubber

Crumb rubber which is powdered form of waste rubber tires was obtained from a local merchant in Taxila, Pakistan. Obtained rubber was further sieved through sieve no. 40. TABLE 3 Composition of waste rubber according to particle size.

TABLE III: Composition of Crumb Rubber

Material	Size
Cuts	>300mm
Shred	50-300mm
Chips	10-50mm
Granulate	1-10mm
Powder	<1mm
Fine powder	<500µm
Carbon products	<500µm

Source: http:// ebooks.narotama.ac.id

IV. Fiber

Here in our project natural fiber was used, commonly known as MUNJIN fiber. Munjin fiber is found in excess quantity to obtain it from North Waziristan. It is bark of Munjin Plant; Munjin fiber is off white in color, 3 to 4 feet in length and 0.3 to 0.5mm in diameter. Munjin fiber is smooth and flexible, having good water absorption which prevents the drain down of pavement. It is valued for use because of its strength durability to stretch affinity for certain dyestuffs and resistance to deterioration in salt water. It is economical for use because it is found in excess quantity in Pakistan. Generally, Munjin fiber is used for making ropes and carpets but it is quite different from sisal. The resultant product of sisal is soft whereas resulting product of Munjin are coarser and stronger. There has been no research work done on the use of Munjin fiber in SMA, so here an attempt is made to use it.

A. Effect of Size of Fiber

Test was performed to check that what size of fiber gives the best results. For this purpose, trial of varied sizes in length of 1.5mm and 3mm having the same diameter was made and samples of same gradation with different fiber size were prepared. After testing it was found that samples with fiber of size 3mm were 20% in stability and rut resistance and were having 15% less flow value. So, here in this study fiber size 3mm in length and 0.3mm in diameter is used.

V. Samples Prepration, Testing, Results

Two types of samples were prepared for Marshall mix design, in first stage samples of conventional SMA with Munjin fiber and SMA 25 was prepared and optimum bitumen content was determined. In second stage crumb rubber was incorporated @ 2%, 4%, 6%, 8%, and 10% to optimum bitumen content by using wet process and Marshal Samples were prepared. Crumb was incorporated in heated bitumen. After preparing samples test was conducted and optimum rubber content was determined. For Indirect Tensile Strength (ITS) test Marshall Samples were prepared at optimum bitumen content and different percentages of Crumb Rubber.

A. Results

Volumetric of Conventional SMA are shown in Table IV.

TABLE IV: VOLUMETRIC PROPERTIES OF CONVENTIONAL SMA

Sample	Stability	Flow	Unit Weight	Air Voids	VFA
4.5	757.47	7.5	2.365	7.11	53
5	841.71	7.8	2.365	6.145	57
5.5	937.65	8.6	2.355	5.8	68
6	995.31	9.56	3.345	4.28	71
6.5	848.78	10.16	2.36	4.06	79
7	823.78	10.6	2.356	4.03	83
7.5	754.34	11.2	2.33	3.90	87

Fig. 1, 2, 3, 4, 5 shows the volumetric of Crumb modified SMA at optimum bitumen content which was found by volumetric of conventional SMA shown in Table IV. Which is 5.8%.

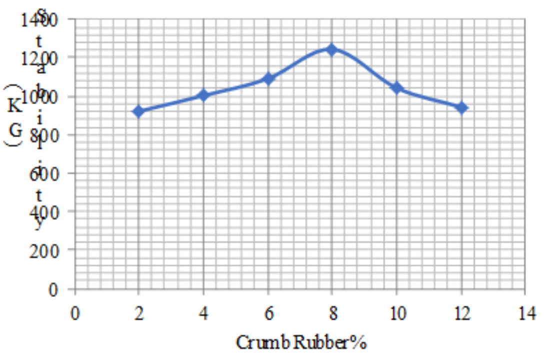

Fig. 1. Stability vs crumb rubber.

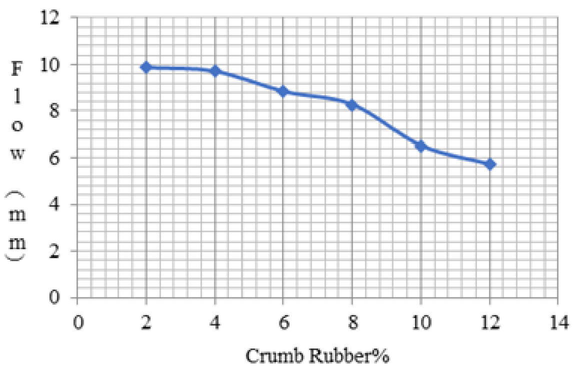

Fig. 2. Flow vs crumb rubber.

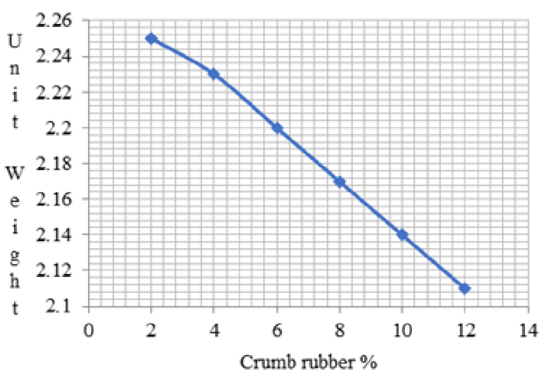

Fig. 3. Unit weight vs crumb rubber.

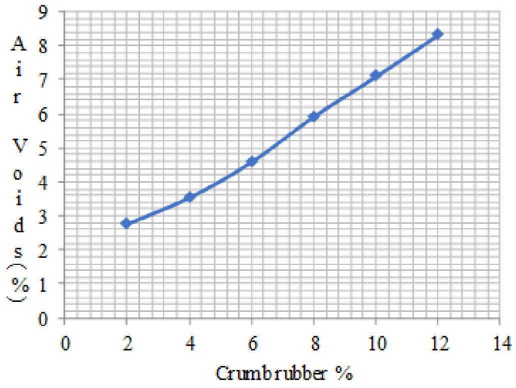

Fig. 4. Air voids vs crumb rubber.

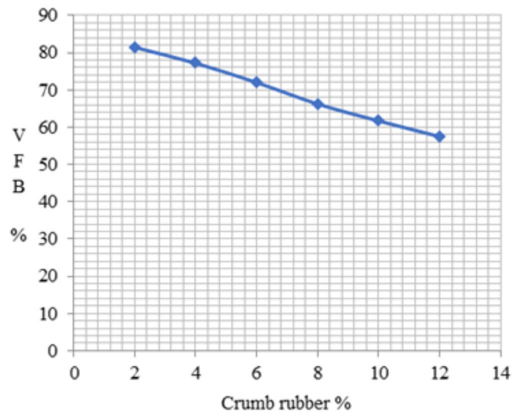

Fig. 5. Voids filled with bitumen Vs C. rubber.

Volumetric of crumb rubber modified asphalt mix gave an optimum crumb content of 4.86%.

1) Moisture sensitivity test and results

This test was conducted in accordance to ALDOT-361-88. Both conditioned and unconditioned samples were radially tested in UTM-25. Samples were prepared at optimum bitumen content 5.8% and with different percentages of crumb rubber 0%, 2%, 4%, 4.5%, 4.86%, 5%, and 6%. While performing the test it was observed that the ITS value increased till 4% of crumb rubber but then it decreased on 5% of crumb rubber, so it was obvious that maximum ITS value lies close to Optimum Crumb Rubber content 4.85% which was found in previous test. So, samples were prepared for percentages of crumb rubber between 4% and 5%. i.e. 4.5% and 4.59%. As shown in Table V. Relation of Crumb Rubber to Tensile strength is shown in Fig. 6.

TABLE V: TENSILE STRENGTH RATIOS

S/No	**Bit. %**	**C R%**	**Avg. Unconditioned Strength (Psi) S1**	**Avg. Conditioned Strength (Psi) S2**	**Tensile Strength Ratio (TSR %) S2/S1**
1	5.8	0	113.48	60.62	53
2	5.8	2	110.25	84.48	76
3	5.8	4	111.68	86.77	77.6
4	5.8	4.5	111.86	90.38	80.7
5	5.8	4.86	115.09	94	82
6	5.8	5	110.82	89.12	80
7	5.8	6	109.54	84.48	77

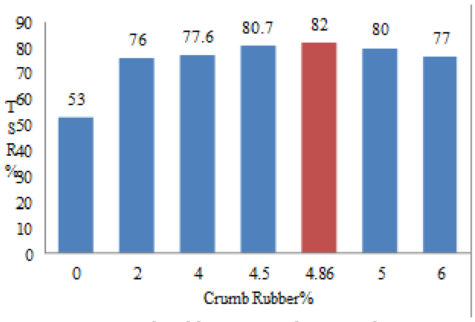

Fig. 6. Crumb rubber vs tensile strength ratio.

VI. Discussion on Results

Optimum bitumen content of SMA is 5.8%. The higher percentage of bitumen proves that SMA is a gap graded mix in which stone to stone content of aggregates provides strength and durability, so to encounter this stone to stone contact and for providing bondage between aggregates a higher percentage of bitumen is required.

Now the question arises that this higher percentage of bitumen in mix will cause the drain down of pavement and higher flow value, so to counter this problem fiber is which prevents drain down of pavement and gives limiting flow value, thus providing a stable, rut and deformation resistance pavement.

Second most crucial point in preparation of mix for pavement is air voids. As in SMA air voids are 4.8% which is quite higher than conventional mix, this higher percentage of air voids proves that the SAM is a gap graded mix, main reason which supports this higher percentage of air voids is that the higher content of bitumen will cause a little bit of expansion in summer when temperature is quite high which results in bleeding and loss of skid resistance, so to cater this higher percentage of air voids are necessary, which will prevent the bleeding and loss of skid resistance.

Third point of discussion is flow values of mix, in SMA we have flow of 8.6mm which is quite reasonable, because the fiber which we use in SMA prevents the drain down of pavement and minimizes the flow of pavement, thus providing a stable and rut resistance pavement. If flow values were higher than pavement would have higher deformation, which will cause its premature and unexpected failure. As SMA uses higher bitumen content so to cater it we should have such an admixture which control its flow and drain down, so the fiber is best alternate to do so

Results show that as we add Crumb rubber in mix having optimum bitumen content (5.8%) air voids goes on increasing and voids filled with bitumen goes on decreasing,and similarly flow values also goes on decreasing. This is because of the fact that increasing cntent of Crumb rubber starts absorbing the bitumen[9].

While performing the tests it was observed that Fiber and crumb rubber in combination has no use, while performing the test it was observed that when munjin fiber was replaced with Crumb Rubber content mix showed approximately same volumetric behavior as was in combination.

Results in Table 5. indicates that TSR value increases as the Crumb rubber content increases till optimum rubber content (4.86%) after that the value start decreasing. Results indicate that TSR value is in range for 4%, 5% and 6% crumb rubber content. Any mix having TSR value greater than 80% is good against moisture sensitivity (Al-shaybani, 2017).

VII. Conclusions and Recommendatios

The study concludes that

By using Munjin fiber in Stone Mastic Asphalt the volumetric properties are enhanced as compared to HMA.

It was also concluded that use of both fiber and crumb in combination is not of much use, as it will make the mix expansive. So, while using crumb rubber in SMA we can exclude the use of fiber.

Further it was concluded that use of crumb rubber in SMA reduced the optimum bitumen content, hence the excess quantity of bitumen which could cause the bleeding or disability in pavement was absorbed by the crumb rubber thus providing a solid surface to ride.

It was concluded that mix showed a strong behavior on optimum bitumen content of 5.8%.

Optimum crumb rubber content at optimum bitumen content was found to be 4.86% of OBC.

At optimum crumb content (4.86%) mix shows excellent behavior against moisture sensitivity, as Tensile strength ratio is also excellent at this content.

It is recommended that waste rubber tire should be used in pavements instead of dumping them around.

It is also recommended that Munjin fiber should also be tried in pavements, as it showed satisfactory results in lab testing.

It is highly recommended to use crumb modified stone mastic asphalt in areas of heavy loading and moderate intensity rain fall.

Future Avenue of the study is to replace crumb rubber in SMA at optimum bitumen content, as this study focuses on addition of Crumb Rubber at OBC.

Refrences

[1] E-Asphalt. (2014). Stone Mastic Asphalt (SMA). [Online]. Available: http://www.e-asphalt.com/sma/index.htm

[2] K. Holíková, Ľ. Jelemenský, J. Annus, and J. Markoš, "Investigation of tyres and coal combustion in a laboratory scale fluidized bed combustor," 2005.

[3] Special Report : Scrap and Shredded Tire Fires, 1998.

[4] R. Muniandy, A. Selim, S. Hassim, H. Omar, Y. Iqob *et al.*, *Laboratory Evaluation of Ground Tire Rubber in Stone Mastic Asphalt*, vol. 1, pp. 53–58, 2004.

[5] N. S. Mashaan, M. R. Karim, M. A. Aziz, M. R. Ibrahim, H. Y. Katman, and S. Koting, *Evaluation of Fatigue Life of CRM-Reinforced SMA and Its Relationship to Dynamic Stiffness*, 2014.

[6] M. Manosalvas-paredes, J. Gallego, L. Saiz, and M. José, "Rubber modified binders as an alternative to cellulose fiber – SBS polymers in stone matrix asphalt," *Construction and Building Materials*, vol. 121, pp. 727–732, 2016.

[7] P. Taylor, I. Hafeez, M. A. Kamal, and M. W. Mirza, *Journal of the Chinese Institute of Engineers an Experimental Study to Select Aggregate Gradation for Stone Mastic Asphalt*, 2014.

[8] I. Hafeez, M. Kamal, M. Mirza, and A. Aziz, "Investigating the effects of maximum size of aggregate on rutting potential of stone mastic asphalt," 2012.

[9] N. S. Mashaan, M. R. Karim, M. A. Aziz, M. R. Ibrahim, H. Y. Katman, and S. Koting, *Evaluation of Fatigue Life of CRM-Reinforced SMA and Its Relationship to Dynamic Stiffness*, 2014.

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