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Experimental Studies on Stone Mastic Asphalt Using Reclaimed Asphalt Pavement for Binder Course

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Abstract: ***Stone Mastic Asphalt (SMA) is a rut resistant layer that counteracts the permanent deformation. Currently SMA mix is relatively costly for paving roads because it requires more durable aggregates, higher asphalt content and typically a modified asphalt binders or fibers. In order to reduce the initial cost of SMA mix other suitable alternative materials or industrial waste such as steel slag, bag house dust, Reclaimed Asphalt Pavement (RAP), Construction and Demolition(C&D) waste, Ferro-Chrome Slag(FCS) and baghouse dust etc. can be used. RAP is found to be effective for SMA mix. RAP reduces the whole cost of the project by replacing the aggregates, and bitumen. The main objective of this study is to evaluate the SMA mixes which utilize RAP with and without an elastomer modifier. The methodology used in this research is material testing, marshall mix design and performance studies including tensile strength ratio, rutting, and fatigue test. It was observed that without modifier 50% of RAP and with modifier 80% of RAP can be used in the SMA mix. The use of an elastomer modifier can enhance the engineering properties of the mix when compared to the conventional SMA mix.***

Keywords: Stone matrix asphalt; Reclaimed asphalt pavement; Marshall properties; Tensile strength ratio; Rutting; Fatigue life

1. Introduction

A good road network plays an important role in the economic development of a country which provides better accessibility to various transportation activities. Most of the Indian roads are flexible pavements. Flexible pavements are subjected to different structural damages such as pothole, raveling, fatigue cracks and rutting etc. due to rapid increase in vehicles population, loads and adverse climatic conditions. Stone mastic asphalt is gap graded hot mix asphalt which provides stable, tough, durable and rut resistant mix. Hence, by using SMA mix a durable pavement can be constructed which serves its design life efficiently. Stone mastic asphalt is a hot mix asphalt which was developed by Germans in the late 1960s (A. Behnood et al, 2012). Stone mastic asphalt is a stone-on-stone like skeletal structure of gap graded aggregate, bonded together by mastic, which contains 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 (K. Shravan et al, 2017). SMA pavements, when designed constructed properly, are a viable solution for prolonging the life of asphalt pavements (Shenghua Wu et al, 2017). The initial cost of stone mastic asphalt is expensive and natural resources are also getting depleted immensely due to the continuous production of aggregates; hence a righteous alternative material is very important. In order to minimize the utilization of natural raw materials, recycled and waste materials can be used, which helps in decreasing the cost of the project and safeguarding the environment. The use of reclaimed asphalt pavement materials in asphalt mixes are currently considered a viable option for repairing in-situ. Some researchers found that use of steel slag as coarse portion of aggregates can improve the engineering properties of the SMA mix (A. Behnood et al, 2012). Large quantity of reclaimed asphalt pavement materials are generated while rehabilitation and reconstruction of pavements. The use of reclaimed asphalt pavement materials in asphalt mixes are asphalt layers and building new asphalt pavement due to the depleting of natural aggregates and the increased cost of asphalt binders (Gubbala chaitanya et al, 2016). RAP materials are generated from milling process. RAP consists of aggregates and a binder, which may or may not have the sufficient quality required for a new design mix due to loss in visco-elastic properties because of ageing process. If these materials are reused in roads, resulting in minimization of environmental impact, reduce the waste stream and also transportation costs connected with road maintenance and construction activities (Brajesh Mishraet et al, 2015). The asphalt mixes prepared with RAP materials shows similar or better performance than conventional asphalt mixes. The bituminous mix which contains RAP is not prone to rutting because the long-term aged binder is mixed with the new asphalt binder, which makes the binder harder (Baoshan Huang et al, 2011). Fatigue life has been found to improve upto certain RAP content further increment in RAP cause damage to the pavement (Gubbala chaitanya et al, 2016). In general practice a small fraction (10 - 30%) of RAP is used in SMA mix. The environmental and financial restrictions are forcing the researchers to incorporate high percentage of RAP in pavement construction. One of the main barrier in achieving this goal is the increased stiffness of the RAP binder (Arshad Hussain et al, 2013). In order to increase the utilization and performance of RAP in SMA mix some additives/modifiers are used (Adam liphard et al, 2016). Elastomer modifier is one such additive developed in Germany which consists of approximate 20% cellulose fibre and 80% elastomeric additive. This new type of modifier is designed for heavy duty roads, improving pavement performance through superior binder properties (Csaba Toth et al, 2015). Therefore, the focus of this study is to obtain a suitable SMA mix with the optimum percentage of RAP material by using elastomer modifier as an additive. In the present study Reclaimed Asphalt Pavement (RAP) has been obtained by scarifying existing distressed asphalt pavements. An investigation has been carried out by replacing 20 mm down natural aggregates, 12 mm down natural aggregates and 6 mm down natural aggregates with scarified asphalt aggregates. A laboratory studies have been adopted to evaluate marshal properties and performance characteristics of stone mastic asphalt. 11 trial mixes were prepared for marshall stability test in which trial one is done for conventional SMA mix and other trials are carried for RAP replacement in SMA mix. Further, performance studies were carried out for conventional SMA mix, optimized RAP with and without elastomer modifier in SMA mix.

1.1 Objectives of the work

- To evaluate the feasibility of using RAP in SMA mixes with baghouse dust as filler.
- To determine the optimum percentage of RAP that can be used in SMA binder course.
- To determine the engineering properties for conventional SMA mix and reclaimed asphalt pavement modified SMA mixes with and without elastomer modifier.

2. Laboratory Investigations

2.1 Aggregates

The aggregates was procured from KMS crushers, Bagalur in Kolar District. The basic tests were performed and the results are tabulated as shown in the below table 1.

2.2 RAP

The RAP material is brought from NH 206, where the existing 2 lane flexible pavement is removed to reconstruct the cement concrete pavement from Karnataka-Andhra Pradesh border to Chittoor. The pavement was 15-20 years old as per the records. The removed pavement layers are dumped in the dumping sites near the highway. The RAP in the form of slabs is brought and processed manually in the college. The RAP material is sieved to get the desired size aggregates. The basic properties of these aggregates are tested and all are within the limit as per MoRT&H specifications. Amount of binder present in the RAP was found out by centrifugal extraction method. RAP contains about 3.09% of bitumen.

Table 1: Tests on natural and RAP aggregates

Tests conducted	Natural aggregate results	RAP results	Specifications as per MORTH 5th Revision
Aggregate Impact Test	17.52%	16.27%	Max 27%
Aggregate Crushing Value	21.30%	18.83%	-
Los Angeles Abrasion Value	17.52%	19.84%	Max 35%
Combined Flakiness and Elongation Index	11.19%	16.83%	Max 35%
Water Absorption Test	0.20%	0.55%	Max 2%
Specific Gravity Test			
20 mm down	2.68	2.51	2.5 to 3.2
12 mm down	2.69	2.59	
6 mm down	2.71	2.54	
Stone Dust	2.72	-	

2.3 Bitumen

The plain VG-30 bitumen was used in this research work. The VG-30 binder was procured from a local contractor. The basic tests were performed and the results are tabulated as shown in the below table 2.

Table 2: Tests on bitumen

Tests conducted	results	Specifications as per IS 73:2013
Penetration Test at 25°C, 0.1mm	64	Min 45
Softening Point (°C), min	48	Min 47
Ductility Test (cm) at 25°C	100+	Min 40
Elastic Recovery Test (%) at 15°C	-	-
Flash Point (°C)	330	Min 220
Fire Point (°C)	350	-
Specific Gravity	1.02	0.97 - 1.02

2.4 Elastomer modifier

The German organization J. Rettenmaier and Sohne have invented few additives/ modifiers in the form of pellets made up of natural or artificial fibres in their research lab facilities. One such additive is cellulose fibres which is utilized in the SMA mixes to prevent bitumen drain down from the surface of aggregates. In 2014-15, J. Rettenmaier and Sohne invented another additive that is an elastomer modifier that consists of 20% of cellulose fibre (ARBOCEL) and 80% of the elastomeric additive. This modifier is intended for hot mix asphalt surface courses of heavy-duty roads and improving pavement performance characteristics. This elastomer modifier is used to modify the bitumen. It is expected to improve stiffness of the mix while somewhat improving low temperature behaviour as well (Csaba Toth et al, 2015). The dosage rate of 15% by weight of elastomer modifier for the total content of bitumen is added to the asphalt mix. The elastomer modifier pellets were directly added with aggregates and heated for 30 seconds at 1700 C then subsequently bitumen is added to the mix.

Figure 1: Commercially available elastomer modifier pellets

Table 1: Characteristics of elastomer modifier

Properties of elastomer modifier	
Content of ARBOCEL ZZ8/1	20%
Content of functional Additive	80%
Colour	Grey cylindrical pellets
Average pellet length	3mm-20mm
Average pellet thickness	3mm-6mm
Bulk density	280g/l-380g/l
Sieve analysis: finer than 3.55mm	Max.8%

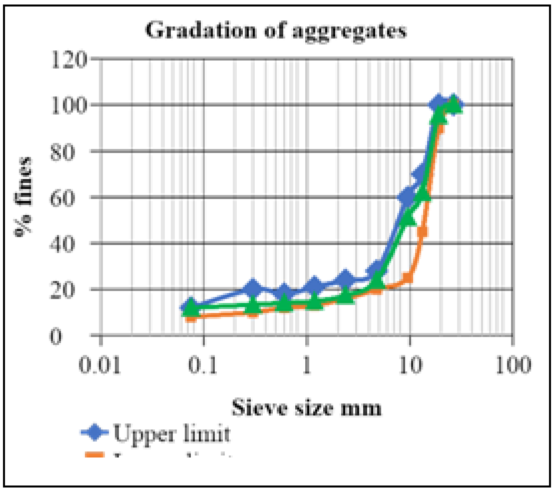
2.5 Fibre and Modifier

Cellulose fibre is used for the present study. Elastomer modifier and cellulose fibre are procured from the "Strategic

Marketing and Research Team" Bengaluru.

2.6 Gradation of aggregates for SMA mix

Gradation of aggregate is one of the basic tests to find the proportions of aggregate to be used in the bituminous mix. The aggregates and their particle size distribution may affect the properties of the bituminous mix. SMA mix performance is mainly dependent on the aggregate gradation. Aggregate gradation is done by trial and error method to obtain individual percentages of different size aggregate that can be used in the bituminous mix confining to the upper and lower limits specified as per MORTH table 500:37.



3. Tests on conventional and nano silica modified DBM mixes

Marshall stability test, moisture susceptibility, immersion wheel tracking test and repeated load test were conducted for conventional SMA mix, RAP modified SMA mix with and without using elastomer modifier. The ITS and rutting specimens were casted for optimum binder and optimum RAP content obtained from marshall test. Finally, the fatigue test is done for all SMA mixes with optimum bitumen and optimum RAP content with and without elastomer modifier using failure load of ITS test at standard test conditions.

3.1 Marshall Stability Test

The marshal stability is defined as the maximum load in kgs that any asphalt mix can withstand at a standard temperature of 600C when it is loaded under particular test conditions. marshall stability test is used to determine the Optimum Binder Content(OBC) and optimum RAP replacement. The OBC of the SMA mix was selected based on 4% of the design air void content. The remaining mix attributes should satisfy the requirements specified in Table 500-41 MORTH. The optimum RAP replacement was selected for a replacement bearing a maximum stability value and also confirming the other marshall parameter.

The specimens are prepared for the obtained gradation by varying bitumen content 0.25%. For 5 different bitumen content i.e., 5.75%, 6%, 6.25%, 6.5%, and 6.75% specimens are prepared. Based on the obtained marshal stability test results the graphs are plotted for volumetric parameters. The results of marshall stability was showed in the table 5. The optimum binder content of SMA mix was found to be 6.4% corresponding to the 4% air voids. For the obtained OBC VMA, stability, flow values were found to be 17.82%, 11.52KN and 3.6mm which are within the standard values. The obtained OBC is used for the further performance studies of SMA mixes.

Then the replacement was carried out using the same gradation with 10%, 20%, 30%, 40%,50% and 60% RAP materials without any modifier and the optimum RAP replacement was determined using marshal properties. 10%, 20%, 30%, 40%, 50% and 60% of RAP has been replaced with normal aggregates and OBC was found to be 6.5%, 6.35%, 6.25%, 6.35%, 6.4% and 6.6% respectively. 50% RAP replacement shows 12.08KN stability. The other volumetric properties like VMA and flow values are 17.68% and 3.75mm. Hence, 50% RAP was selected as optimum replacement as it satisfies the SMA mix requirements as per MORT&H.

Without modifier 50% RAP can be effectively used, if modifier is added to the mix it enhances the mix properties and it increases the RAP replacement percentage. Hence, elastomer modified SMA mix samples were prepared for 60%, 70%, 80% and 90% RAP replacements with virgin aggregates and OBC was found to be 6.6%, 6.5%, 6.4% and 6.5% respectively. From the test results it was found that 80% RAP gives maximum stability value that is 12.8KN. The other parameters are also within the limit as per MORT&H specifications. Hence 80% RAP with 15% elastomer modifier was considered for further performance tests.

Table 5: Marshall properties of SMA mix

Type of SMA mix	Con. SMA mix	SMA mix with 50% RAP	SMA mix with 80% RAP using modifier
Marshall stability (kN)	11.2	12.08	12.8
Flow value (mm)	3.8	3.75	3.5
Air voids (%)	4	4	4
Unit weight (g/cc)	2.345	2.333	2.328
Voids in mineral aggregates, VMA (%)	17.82	17.75	17.68
Voids filled with bitumen, VFB (%)	79	78.5	78

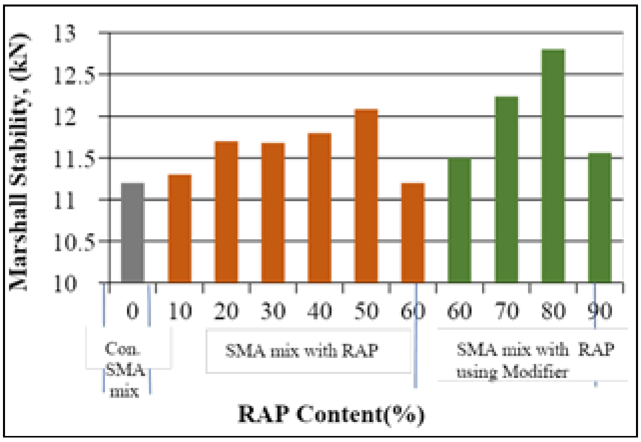


Figure 3: Variation of stability values for Different SMA mixes

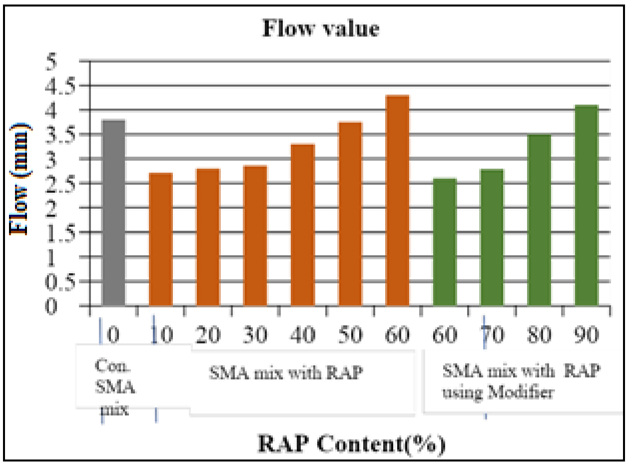


Figure 4: Variation of flow values for different SMA mixes

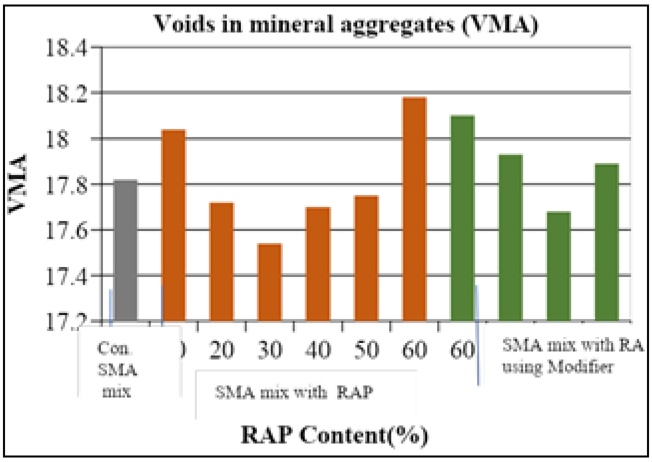


Figure 5: Variation of VMA values for different SMA mixes

3.2 Draindown test

The fines and bitumen that separates and flows out from the bituminous mix during storage and transportation is called draindown of the bituminous mix. The effect of binder content on the drainage characteristics of the uncompacted mix is very important to address because draindown of the binder is one of the common issues in the SMA mix. 0.3% cellulose fibres are added to the SMA mix to prevent draindown problem. The test was done according to ASTM D 6390. This test was done in order to make sure that binder drain off should be less than 0.3%. The Draindown test was done on a conventional SMA mix, optimized RAP SMA mix without modifier as well as optimized RAP SMA mix with modifier and the results are 0.019%, 0.022% and 0.020 % respectively. The results obtained are within the limit as specified in MORT&H.

3.3 Moisture susceptibility

The main cause of premature cracking in the bituminous surface roads is the existence of water on the surface of roads, and the binder cannot retained on the aggregates in the presence of moisture. Therefore, it is important to conduct tests on moisture sensitivity. In the present study water sensitivity is determined by tensile strength ratio test. An indirect tensile strength of bituminous mix is carried out as per AASHTO T 283 guidelines. To perform this test, a load will be applied to the plane of the vertical diameter of the cylindrical sample and it is conducted at room temperature. This test result are tabulated below and it can be utilized to find out the long-term stripping sensitivity of the asphalt mix. The tensile strength ratio of conventional SMA mix is 90.17%, for 50% RAP SMA mix it is 92.79% and for optimized RAP without a elastomer modifier is 94.38%, obtained results are within the limit as per MORT&H. The test results shows that the SMA mix with 80% RAP and elastomer modifier is more moisture susceptible than other mixes.

Table 6: Indirect tensile strength test results

Type of Mix	Condition	Tensile Strength (kPa)	TSR value
Conventional SMA mix	Dry	662.53	90.17
	Partial saturation	625.32	
50% RAP replacement SMA mix	Dry	670.35	92.79
	Partial saturation	621.99	
80% RAP replacement SMA mix using modifier	Dry	368.50	94.38
	Partial saturation	332.26	

3.4 Rutting test

Rutting test on the SMA mix (binder course) is performed to evaluate the resistance to permanent deformation. Immersion wheel tracking equipment measures the rutting effect of the SMA mix sample specimen by moving the rubber wheel on it. Rutting is measured in terms of rut depth on the specimen. In this device, various parameters are provided, such as wheel type (planar and threaded), the pressure of the tire, road surface temperature, and thickness of the sample to be tested. The test is conducted at room temperature using the threaded wheel at a tire pressure of 5.6 kg/sq.cm. Two different thicknesses of specimens are used to do the test(45mm and 75mm) for all three mixes that is conventional SMA mix, SMA mix with 50% RAP and SMA mix with 80% RAP using elastomer modifier. The graphical representation of the results is shown below.

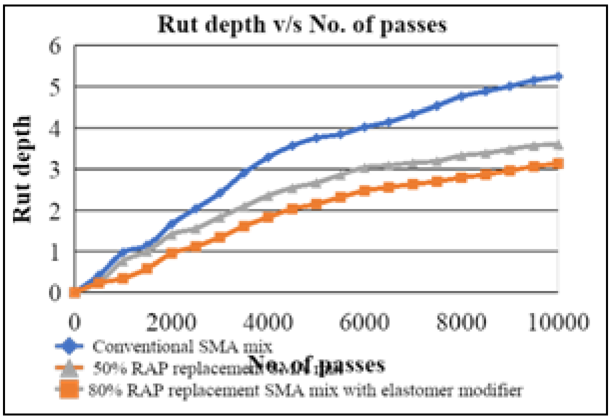


Figure 6: Rutting characteristics for SMA mix of 50mm thickness

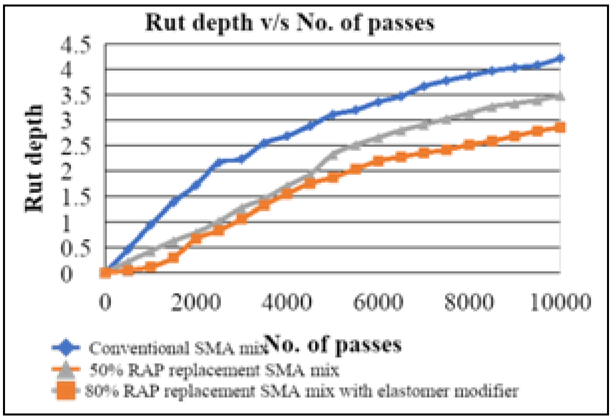


Figure 7: Rutting characteristics for SMA mix of 75mm thickness

The rut depth of conventional SMA mix, 50% RAP modified SMA mix and 80% RAP modified SMA mix with elastomer modifier for 45mm and 75mm thick beam are 5.24, 3.61, 3.14, 4.22, 3.48, and 2.86mm respectively. From the test results, it was observed that SMA mix with 100% virgin aggregates shows less resistance when compared to the recycled asphalt pavement modified SMA mix. SMA with elastomer modifier shows high rut resistance.

3.5 Repeated load fatigue test

The fatigue properties of asphalt mixes are important considerations in pavement design because fatigue failure is one of the major problems especially, in lower layers of asphalt pavements. Fatigue failure is one of the common distresses observed in pavement due to repeated application of loads. The fatigue properties of the SMA mix is evaluated by repeated load test. Repeated load test is conducted to know the numbers of load repetitions that SMA mix can withstand. The repeated load was applied at 1Hz with a constant stress load (10% stress load). The test is carried out at a 250 C temperature. The graphical representation of results are shown below. The fatigue life of conventional SMA mix, 50% RAP modified SMA mix and 80% RAP SMA mix with elastomer modifier can withstand are 12377, 8890 and 24124 number of load repetitions respectively. SMA mix with 80% RAP using elastomer modifier enhances the fatigue life of the mix.

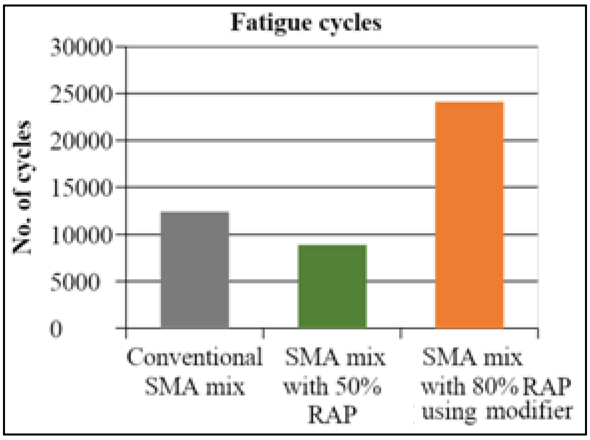


Figure 8: Variation of number of cycles for different SMA mixes at 10% failure load

4. Conclusions

The following conclusions were drawn from the present work

1) From marshall stability test results it is found that 50% replacement of RAP without elastomer modifier in SMA mix has shown better marshall properties.
2) It is observed that the stability value of 80% RAP replacement in SMA mix using elastomer modifier is 1.14 times greater than the conventional SMA mix and other marshall properties are within the specified limit as per IRC: SP: 79 and MORT&H..
3) Draindown test results for conventional SMA mix, 50% RAP without a modifier, and 80% RAP with modifier SMA mixes are well within the limits as per IRC: SP: 79 and MORT&H..
4) It is observed that TSR value of SMA mix with 80% RAP using elastomer modifier shows better results compared to conventional SMA mix and SMA mix with 50% RAP. TSR value of 80% RAP modified mix is 1.04 times greater than conventional SMA mix.
5) The test results indicated that the SMA mix with 50% RAP and SMA mix with 80% RAP using elastomer modifier are more rut resistant when compared to the conventional SMA mix..
6) The fatigue value of SMA mix with 80% RAP using elastomer modifier is found to be 1.95 times higher than conventional SMA mix. The fatigue life of SMA mix with 50% RAP without using modifier is lesser than other two mixes.
7) From the test results, it can be concluded that without modifier 50% of RAP can be used but using an elastomer modifier up to 80% RAP can be used in SMA mix without compromising its engineering properties.

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