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Laboratory investigations and performance evaluation of stone matrix asphalt as a wearing course using three different fibers

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ABSTRACT

Bituminous mixtures are used as wearing and base course layers in a pavement structure and the performance of these mixes can be defined by its resistance against deformation, fatigue cracking, damage due to moisture and overall stiffness of the mixture. Rutting is one of the most important factors that lead to permanent failure of flexible pavements. The stone matrix asphalt (SMA) mixture is known to be highly rut resistant than other conventional wearing courses such as bituminous concrete. This paper describes the experimental examination conducted on stone matrix asphalt (SMA) mixes prepared using VG 30 grade of bitumen and different types of fibers such as cellulose fiber, coconut fiber, glass fiber and jute fiber as their additives. Results were then collated with SMA mixes prepared with different types of fibers. Investigation work comprises SMA mix design, static indirect tensile strength (ITS) and drain down test. From the test results, it was perceived that SMA with cellulose fiber has higher Marshall Stability and slightly lower drain down percentage as compared to all other fibers used. But indirect tensile strength for SMA mix prepared with jute fiber was higher than all other mixes.

Keywords: Cellulose fiber; Coconut fiber; Glass fiber; Jute fiber; ITS; Drain down.

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1. INTRODUCTION

Stone matrix asphalt (SMA) is a gap graded mixture containing high amount of coarse aggregate and less percentages of fine aggregate with high fraction of mineral filler and binder content (Fig.1). Normal stone matrix asphalt (SMA) mix comprises of about 70-80% of coarse aggregate whereas conventional mixes contain about 40-60% of coarse aggregate. In SMA mix, the normal binder content is more than 6%. Strength of these mixtures comes from the stone on stone contact imparting from the coarse aggregate skeleton and durability comes from the high binder content. The strength and performance for stone matrix asphalt (SMA) is generally high as compared to other asphalt mixes (bituminous concrete mixes) (Singh et al., 2017; Singh et al., 2019; Singh et al., 2019).

Due to gap gradation, binder may drain out from the mix at the time of placing, production and storage. This can be overcome by the addition of a stabilizer. This paper includes the addition of four different stabilizer additive i.e. cellulose fiber, coconut fiber, glass fiber and jute fiber. The performance of the mix with different fibers is evaluated and then compared. The performance studies such as indirect tensile strength test (ITS) (ASTM, 2017) and drain down test (ASHTO, 2017) were conducted and the results were compared for four different stabilizing additives.

Stone matrix asphalt was first developed in Germany in 1960 and since then many case studies have been conducted over stone matrix asphalt (Bindu and Beena, 2010;

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Brian et al., 2010; Brown et al., 1997; Ahmadinia et al., 2011; Sarang et al., 2015; Labbo et al., 2016; Awanti, 2013; Moghaddam et al., 2012; Rongali et al., 2013; Mogawer and Stuart, 1995). The main objectives of this study was to determine the optimum binder content for stone matrix asphalt (SMA) with VG-30 grade bitumen using four

Fig. 1. SMA mix

different fibers namely cellulose, coconut, glass and jute by using Marshall method of mix design (Asphalt Institute, 2009). Secondly, to determine the static indirect tensile strength for SMA mix with VG-30 grade bitumen using four different fibers at room temperature. Thirdly, to evaluate the drain down percentage for stone matrix asphalt (SMA) with VG-30 grade bitumen using four different fibers.

2. MATERIALS AND METHODS

2.1 Materials Used

2.1.1 Coarse Aggregates

Coarse aggregates were procured from the stone crusher situated at Anandpur Sahib, Punjab. Only aggregate retained on 2.36 mm IS sieve were selected for mix preparation as per IRC:SP: 79-2008 (Indian Roads Congress, 2008). Table 2 presents the properties of slected aggregates.

2.1.2 Fine Aggregate

Fine aggregates were also procured from the stone crusher situated at Anandpur Sahib, Punjab.

2.1.3 Mineral Filler

Stone dust was used as a mineral filler for the preparation of SMA mixture as per IRC:SP: 79-2008 (Indian Roads Congress, 2008).

2.1.4 Bitumen

Viscosity grade VG-30 was used as a binder for preparation of fiber stabilized SMA.

2.1.5 Stabilizer Additive

Natural cellulose fiber (pelletized form, melting point of 467°C), coconut fiber (max. 6 mm length, melting point of 120°C), glass fiber (length 5 mm, melting point of 1200°C) and jute fiber (length up to 6 mm, ignition temperature of 193°C) are used as an additive with a dosage of 0.3% by weight of total mix (Behnood and Ameri, 2012) (Fig. 3,4).

2.2 Mix Design of SMA Layer

After finalizing the gradation for the bituminous mixes (as shown in Table 1 and Fig. 2), the next step was to determine the optimum binder content (OBC) using Marshall mix design method. 9 Marshall samples were casted at binder content of 6%, 6.5% and 7% (by weight of mix), (3 samples at each binder percentage). A fiber content of 0.3% by weight of mix was selected for all samples. The mixing temperature and the compaction temperature were160°C and 140°C respectively.

For casting the Marshall sample 1200 grams of aggregate were taken and mixed with corresponding bitumen content by weight of mix and 0.3% fiber by weight of mix at a mixing temperature of about 160°C. The mixing of aggregates and bitumen should be done properly so that every aggregate is coated with bitumen properly. The Marshall mold, collar and the hammer were preheated in the oven. The prepared mix was filled in the mold. The specimen was compacted by giving 50 blows on each face of the sample by a hammer of weight 4.5 kg and a drop of

Table 1. Gradation for SMA (Asphalt Institute, 2009; Indian Roads Congress, 2008)

Sieve Size (mm)	Limits as per IRC SP-79		Mid-value (Percentage Passing)	Cumulative percentage retained	Percentage retained
	Lower	Upper			
19	100	100	100	0	0
13.2	90	100	95	5	5
9.5	50	75	62.5	37.5	32.5
4.75	20	28	24	76	38.5
2.36	16	24	20	80	4
1.18	13	21	17	83	3
0.6	12	18	15	85	2
0.3	10	20	15	85	0
0.075	8	12	10	90	5
Pan	-	-	-	100	10

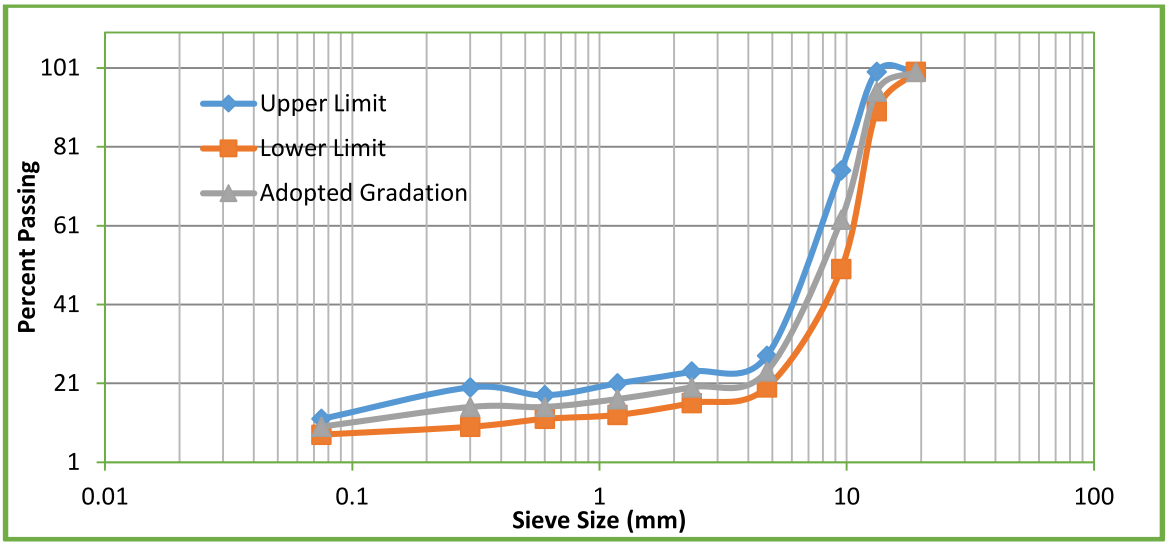

Fig. 2. Gradation chart for SMA

Table 2. Properties of coarse aggregate (MoRTH, 2013)

Property	Results	IRC:SP: 79-2008 requirements
Aggregate impact value	18.5%	24% max.
Los angles abrasion value	16.40%	25% max.
Water absorption	0.4%	2% max.
Specific gravity test	2.638	-

Fig. 3. Cellulose fiber and jute fiber

Fig. 4. Glass fiber and coconut fiber

457 mm. Load was applied perpendicular to the axis of the specimen at a constant deformation rate of 51 mm per minute.

The thickness and diameter of each specimen was 63.5 mm and 101.6 mm respectively. After preparing the Marshall samples, they were left undisturbed for 24 hours and then the samples were extracted from their molds (Fig. 5). According to IRC, 2008, SMA Mix should fulfill requirement given in Table 3.

2.3 Volumetric and Marshall Properties

Marshall samples were removed from their molds, the density of each sample was determined. Based on this data, volumetric analysis of the sample was done and voids in mineral aggregates (VMA), voids filled with bitumen (VFB), and percentage air voids were calculated (Table 4).

Further the Marshall stability and flow values were determined. Marshall test was conducted in order to determine the resistance to plastic deformation of cylindrical specimen when loaded at its periphery at a rate of 50.8 mm/minute. The test procedure is as given in ASTM D 6927. Before testing for its stability and flow values the Marshall samples were kept in a water bath at60 °C for 30-40 minutes.

Fig. 5. Prepared Marshall sample of SMA mixture

Table 3. SMA mix requirements (Indian Roads Congress, 2008)

Mix Design Parameters	Requirement
Air void content, %	4.0
Bitumen content, %	5.8 min.
Celluloid fibers	0.3% min. by weight of total mix
Voids in Mineral Aggregates (VMA), %	17 min.
VCA mix, %	Less than VCA (dry rodded)
Asphalt drain down, %	0.3 max.
Tensile strength ratio, %	85 min.

Fig. 6. Empty wire basket and wire basket with SMA mix in oven

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2.4 Drain Down Test

This test is done specially for the mixture such as stone matrix asphalt and open graded asphalt in which we calculate the amount of binder drain down of an uncompacted mix. Drain down is defined as the portion of mix which leaves itself from the sample and flows downwards when it is held at high temperatures. This problem can be faced during the transport, placement and production storage of the mixture and is significant for those mixtures having high coarse aggregate content i.e. stone matrix asphalt in which voids are much larger in an uncompacted mix which results in high drain down as comparison to other conventional mixes (ASTM, 2017).

Drain down test was conducted as per AAHTO T305 on the mixture prepared at optimum binder content and was poured into the wire basket having a sieve cloth of size 6.3 mm (ASHTO, 2017) (Fig.6).

Then a catch plate was taken and weighed and the basket with the mixture poured in it was also weighed. The basket was placed over the catch plate and kept in an oven for 1 hour ± 5 min. at 120°C to 175°C with ± 2°C of the set temperature.

After 1 hour, the binder from the mixture, drained into the catch plate was again weighed. Finally, the drain down as a percentage of the mass retained to the total mass of the mixture was calculated as:

Drain Down (%) = {(Z-Y)/(X-W)}×100

Where,
W = Mass of empty wire basket, g
X = Mass of wire basket with sample, g
Y= Mass of empty plate, g
Z = Mass of catch plate with drained sample, g

2.5 Indirect Tensile Strength (ITS) Test

Since, SMA is not that much strong in tension as it is in compression, the indirect tensile strength test was conducted to find out the tensile properties of the stone matrix asphalt mixture because the resistance to fatigue cracking in the pavement is directly dependent on the tensile properties of the mixture. Therefore, ITS is an indicator of the tensile strength of the mix which resists against the failure of fatigue, rutting and temperature cracking.

The test was conducted as per ASTM D 6931 (ASTM, 2017) and at room temperature of about 27°C. The loading strip is 12.7 mm wide and 70 mm long. ITS value can be calculated using the following equation:

$$ITS\ \ (KPa) = \frac{2000 \times P}{\pi \times d \times h}$$

where,
P = maximum load in Newton,
d = diameter of sample in mm,
h = height of sample in mm

3. RESULTS AND DISCUSSION

From the experimental investigation, it was seen that there is a small change in the optimum binder content in the SMA mix using different fibers, but the stability was more for the control mix i.e. using cellulose fiber than all other mixes.

From the graphs (Figs. 7-11) it was observed that apart from cellulose fiber, jute fiber was showing the better properties with respect to other two fibers i.e. coconut and glass fiber. There was no such difference in the values of drain down from all these fibers and all the values were in specified limits as mentioned in IRC:SP:79-2008 (Indian Roads Congress, 2008).

Table 4. Results of volumetric analysis

Volumetric properties	Results of SMA mix			
	Cellulose fiber	Coconut fiber	Glass fiber	Jute fiber
OBC, (% by wt. of mix)	6.64	6.47	6.5	6.5
Density, g/cc	2.323	2.288	2.285	2.296
Air Voids, %	4	4	4	4
VMA, %	19.12	19.62	19.73	19.35
VFB, %	84.5	79.84	79.72	81.67
Stability, kg	1116	742.47	751.07	957.47
Flow value, mm	3.8	4.52	4.57	4.4

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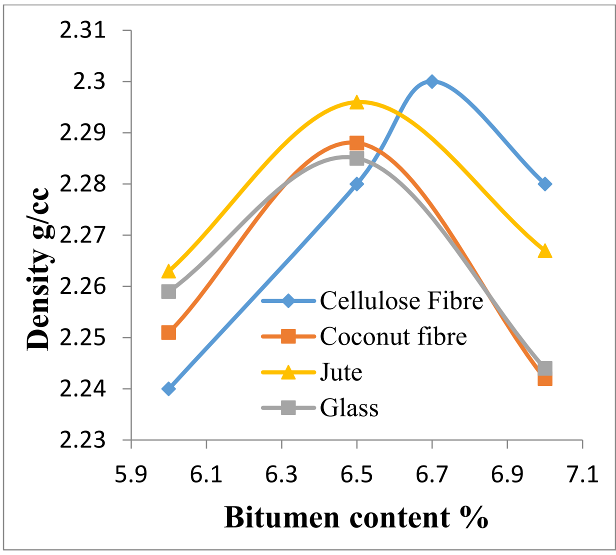

Fig. 7. Density results for different fibers

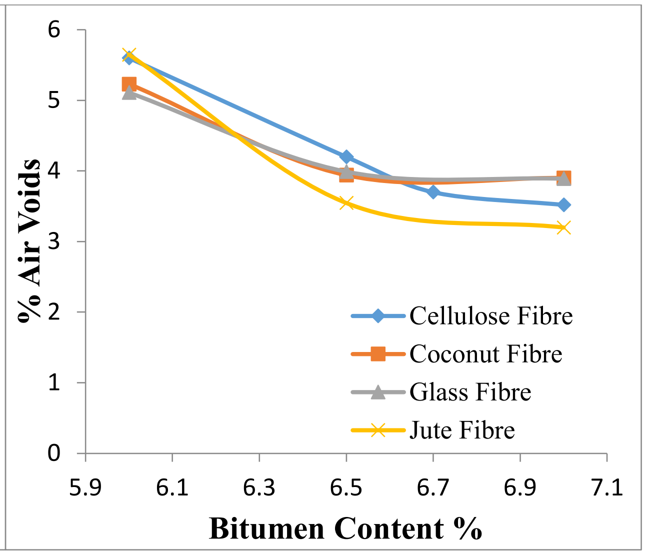

Fig. 8. Air voids results for different fibers

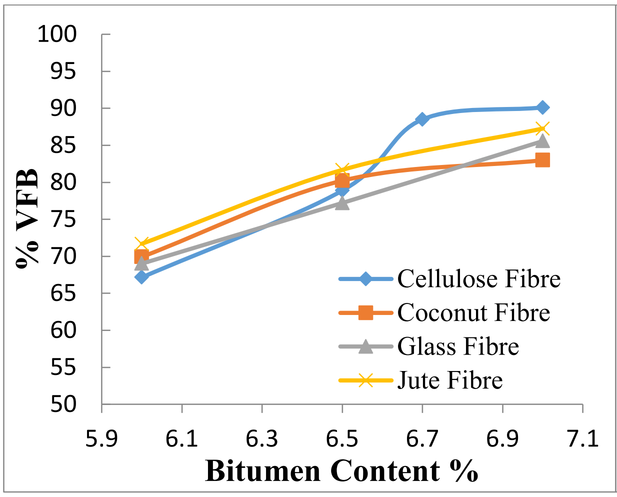

Fig. 9. VFB results for different fibers

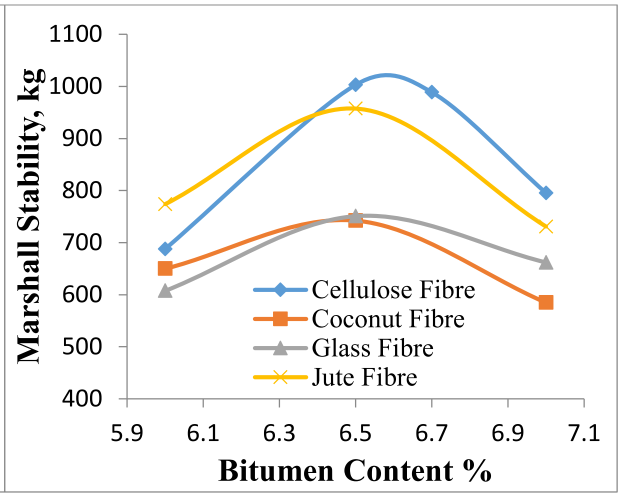

Fig. 10. Stability results for different fibers

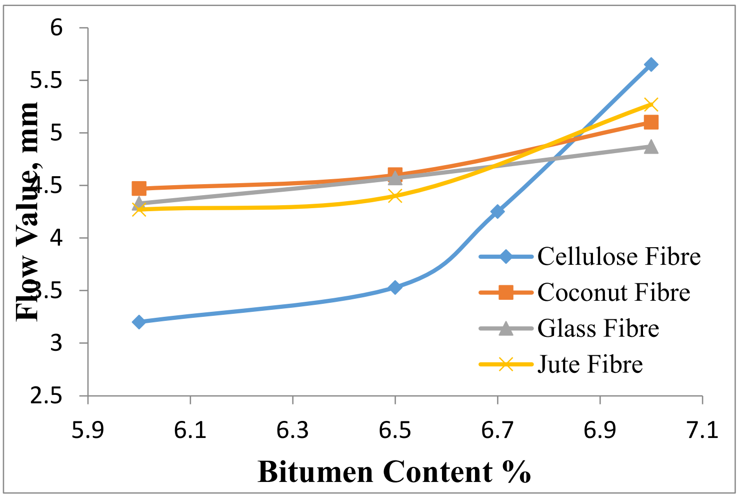

Fig. 11. Flow results for different fibers

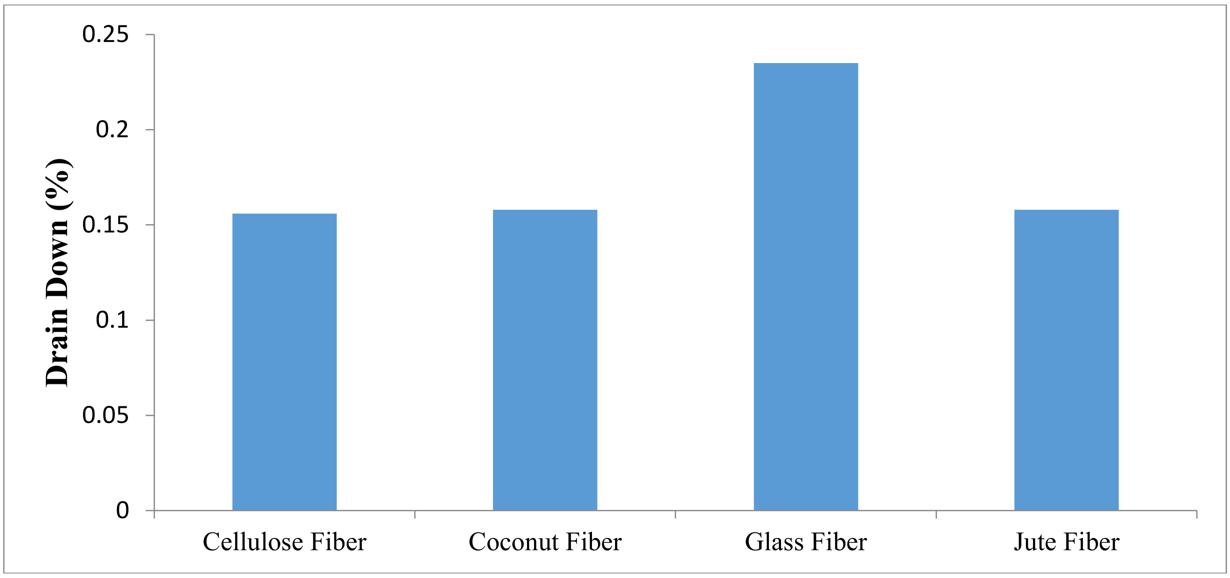

Fig. 12. Drain down results for different fibers

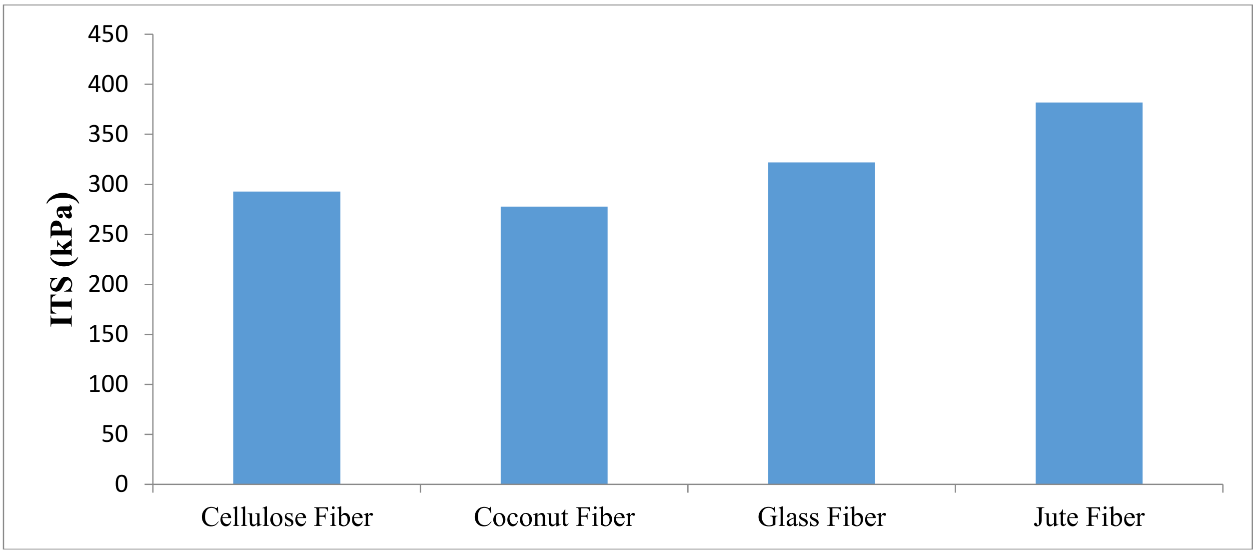

Fig. 13. ITS results for different fibers

From Fig. 12, it was observed that drain down % for cellulose fiber was minimum (i.e. 0.156%) and drain down value coconut fiber and jute fiber was identical (i.e 0.158 %). However, glass fiber showed maximum drain down percentage among all the mixes (i.e. 0.235%). Also, coconut fiber melted up during drain down test because melting point of coconut fiber is also around 120°C. From the Fig. 13, it has been observed that indirect tensile strength for jute fiber is higher than all other fibers even more than cellulose fiber.

4. CONCLUSION

From the study it was concluded SMA with jute fiber as additive has more indirect tensile strength than other three mixes of stone matrix asphalt (SMA) while the SMA with cellulose fiber and SMA with coconut fiber have nearly the same ITS value.

The drain down test results shows that the cellulose fiber shows minimum drain down although the drain down results of all types of additives lies within specified limits. The test indicates that the drain down potential of a mix with cellulose fiber is minimum during field production. The role of additive is to stiffen the mastic and thereby reducing the drainage of the mixture at high temperatures during storage, transportation, placement and compaction of SMA mixture.

Stone matrix asphalt (SMA) with cellulose fiber shows better volumetric properties than other SMA mixes with other fibers. Since the availability of cellulose fiber is typical and results shows that there is no such difference between the cellulose and jute fiber, we can use jute fiber also in the construction SMA pavement.

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