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STRENGTH ASSESSMENT OF ASPHALTIC CONCRETE USING BITUMEN, NATURAL FIBRE AND STONE DUST

ODREĐIVANJE ČVRSTOĆE ASFALTNOG BETONA KORIŠĆENJEM BITUMENA, PRIRODNIH VLAKANA I KAMENE PRAŠINE

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- bituminous concrete
- sisal fibre
- natural fibre
- stone dust
- Marshall test

Abstract

Bituminous concrete (BC) mixes were experimented with different binding content (4-6 %) and with different fibre content (0-0.8 %). In this study, viscosity grade VG-30 bitumen is used as a binding agent and sisal fibres for bituminous mixes. The chief purpose of this research work is determination of optimal bitumen content of bituminous concrete by Marshall Test, testing the Marshall properties of bituminous mixtures with and without sisal fibre, and using filler as stone dust, evaluation of BC mixes with and without sisal fibre by draindown test, evaluate and compare the bitumen sample with or without fibre using the UPV test. It was observed that after adding sisal fibre to 0.4 % corresponding to fibre length 10 mm and bitumen content 5 %, the stability of the mix increases but beyond 0.4 % of fibre content stability starts decreasing. The study shows decrease in air void and flow value by increasing fibre content to 0.4 %, by keeping fibre length to 10 mm corresponding to bitumen content of 5 %. After mixing the sisal fibre coated with SS-1 emulsion, the draindown of the mix reduces or stops which further indicates good bitumen characteristics. Ultrasonic test performed on the mix after adding the sisal fibre indicates the increase in density i.e,, voids were filled by fibre and viscosity as compared to the plain mix.

Ključne reči
- bitumenski beton
- sizal vlakna
- prirodna vlakna
- kamena prašina
- Maršalov test

Izvod

Izvedeni su eksperimenti sa mešavinama bitumenskih betona (BC) sa različitim sadržajem veziva (4-6 %) i vlakana (0-0,8 %). U ovom radu, bitumen stepena viskoznosti VG-30 se koristi kao vezivno sredstvo i vlakna sizala za bitumenske mešavine. Osnovna svrha u radu je određivanje optimalnog sadržaja bitumena u bitumenskom betonu Maršalovim testom, ispitivanje Maršalovih svojstava bitumenskih mešavina sa i bez sizal vlakana i korišćenjem kamene prašine kao punioca, procena BC mešavina sa i bez sizal vlakana drenažnim ispitivanjem, procena i upoređivanje uzorka bitumena sa ili bez vlakana primenom UPV testa. Uočeno je da se nakon dodavanja sizal vlakana do 0,4 %, što odgovara dužini vlakna 10 mm i sadržaju bitumena 5 %, stabilnost mešavine povećava, ali preko 0,4 % stabilnosti sadržaja vlakana počinje da opada. Studija pokazuje smanjenje vazdušne šupljine i vrednosti tečenja povećanjem sadržaja vlakana na 0,4 %, zadržavanjem dužine vlakana na 10 mm, što odgovara sadržaju bitumena od 5 %. Nakon mešanja sizalnog vlakna obloženog SS-1 emulzijom, dreniranje mešavine se smanjuje ili zaustavlja što dalje ukazuje na dobre karakteristike bitumena. Ultrazvučno ispitivanje mešavine posle dodavanja sizal vlakana ukazuje na povećanje gustine, na pr. šupljine su ispunjene vlaknima i viskoznost u poređenju sa običnom mešavinom.

INTRODUCTION

Development of roads is important for the development of any country as it is the cheap and best mode of transportation, and normally flexible pavements are adopted. As natural fibre is economical in India and hence can be used to make the mix dense in case of flexible pavement which is nowadays the focusing area of most researchers. Hence, sisal fibre can be used to provide the strength to flexible pavement and make the pavement construction economical. Sisal fibre is obtained from leaf pores and skin after disposing of the pulp. Neither dust debris nor water and moisture are appealing to sisal fibres and use of sisal fibre provides improved strength, durability, and prevents drain. In the present study the length of sisal fibre is used in between 6 to 18 mm with the diameter of 0.2 to 0.6 mm. The Marshal stability test was conducted to determine the value of optimal content of fibre and bitumen, and various parameters like voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and air content (VA) are used in the test. Ultrasonic pulse test is conducted on plain and reinforced sample to study the cracks and voids in mix samples. A good composition of bitumen creates durable, environment friendly, strong, and cost-effective samples. This research tries to reap the essential and fulfil by making ready number of samples at bituminous mixes with various proportions and take a look at them to search out the optimal value.

Literature review

Bituminous concrete (BC) is used as a flexible pavement wearing path. Bituminous concrete layers are applied in three different thicknesses of layers: 30, 40, and 50 mm. Industrial waste is applied to bituminous layers for decades, including steel slag. There are about ten million tons of stainless-steel slag produced in India every year, 70 % of which are used in the cement industry. The optimal steel slag percentage, which can partially replace stone dust, for viscosity grade-30 and crmb-60 sample mixes are determined in this study, and this is 10 %. Then the impact on Marshall properties of this optimal steel slack is investigated, /1/.

Experiments were carried out on various bitumen samples reinforced with waste plastic, waste rubber, and fly ash, corresponding to their optimal content in the sample. Marshal stability test was conducted on various samples using same content of rubber and waste plastic (in the proportion of 4 to 8 % by wt. of bitumen) along with various percentage of blended bitumen content (proportion of 4 to 8 % of entire blend). The material used as filler is also substituted by stone dust (up to 2 % by wt. of total mix) and fly ash up to 50 %, corresponding to total weight content. Statistical analysis such as correlation and regression are done to find the relationship between variables, in particular, which affect dependent parameters. (Stability is affected by plastic waste and the flow value has been impaired by bitumen), /2/.

Researcher on aggregate classification of the mixes according to MORTH requirements was regularly varied 4 to 7 %, the fibre content was kept between 0 to 0.5 % by weight of total mix. As per preliminary study, the Marshall properties of fly ash were satisfactory and therefore used for mixing afterwards. The optimal fibre content for BC and SMA was 0.3 % for the Marshall mix, although the binder content of OBC was 5 and 2, respectively. In the same way, Optimal Binder Content (OBC) was 5 and 5.2 %, respectively, shown by bituminous concrete and stone matrix asphalt, /3/.

The IRC:SP:53-2010 provides the guidelines related to the usage of modified bitumen in various road construction works as modified bitumen enhances the service life of top layer of the pavement, /4/.

The Marshal stability test is conducted on stone matrix asphalt mixture stabilized with plastic strips by varying bitumen content 6-8 % and plastic content 6-12 %, /6/.

The adequacy of coir fibre as reinforcing material is observed on mixes and their performance is analysed. The author concluded optimal bitumen content as 5 % corresponding to optimal fibre length 0.46 % in reinforced bitumen mix, /7/.

The major addition in the 5^{th} revision of specifications for road and bridge works cover stone mastic asphalt, micro surfacing, sand asphalt base course, and geo cells for use in base and sub-base pavement, /8/.

The rheological properties of the bitumen mix reinforced with fibre of cellulose oil palm was observed. The level of stresses was reduced in the mixture, and it was concluded that corresponding to fibre content of 0.6 %, the initial stresses were at the lower level, /9/.

The bitumen mixture was mixed with natural fibre and study proved that the asphalt binding system was improved as the improvement in paving performance was observed. It also helped to improve the tiredness and resistance of pavement distress when admixed with natural fibre, /10/.

The code provides the guidelines for gap graded mixes with a bitumen rubber binder to be used in high volume and other roads, /11/.

The authors have investigated the draindown property of the mixture of stone asphalt incorporated with conventional bitumen with non-conventional sisal fibre, /12/.

The marshal stability test was conducted to study the drying properties of stone asphalt matrix when it was admixed with non-conventional sisal fibre. The Marshal properties of the mix improved significantly, corresponding to optimal content of fibre as 0.28 %, /13/.

The authors have conducted the comparison between the bitumen modifications by using polypropylene fibre and sisal fibre to avoid the cracks and failure of the bitumen surface, /14/.

Various tests such as compression test, split tensile strength test and permeability tests were conducted on the concrete sample reinforced with banana fibre and properties were compared with plain concrete, /15/.

In the study, the stone dust was replaced with steel slag in the bitumen layers to optimise the cost of construction. The optimal content of steel slag was investigated corresponding to VG-30 grade of bitumen and further Marshal properties are studied, /16/.

Authors explored the use of waste plastics, waste rubber, and fly ash as a road construction material. The results proved that a mix of 5 % each of waste plastic and rubber was found as optimal percentage as a filler material, /17/.

Authors performed the evaluation of relative importance index of 16 performance indicators and found that deflection and potholes have maximal index value for the flexible pavement, /18/.

The bitumen mix is replaced with local fibre and the bitumen content varied between 4-7 %. Further, various tests such as draindown test, static indirect tensile strength and static creep testing were conducted on the bitumen mix, admixed with fibre, /20/.

The authors have studied the benefits of sisal fibre as an additive in bituminous concrete and results proved that the modified bitumen shows better stability, durability, and flow value, /20/.

A study has been carried out to evaluate the effect of natural fibre as an additive in bituminous concrete (BC) and the improvement in Marshal stability, drainage properties, and indirect tensile strength of the BC was observed, /21/.

Objectives of study

Bituminous concrete (BC) mixes were experimented with different binding content (4-6 %) and with different fibre content (0-0.8 %). In this study, viscosity grade VG-30 bitumen is used as a binding agent and sisal fibres for bituminous mixes. The main aim of research is to:
- determine optimal bitumen content of bituminous concrete by Marshall test;
- test the Marshall properties of sisal fibre mixtures with and without sisal fibre, and using stone dust as filler;
- evaluate Bituminous concrete mixes with and without sisal fibre, done by test as the ‘draindown’ test;
- evaluate and compare the bitumen sample without and with the fibre using the UPV test.

Materials

Experiments are carried out on materials such as aggregate, bitumen, fillers, fibre, and bituminous concrete tests.

Aggregates

Generally, natural coarse aggregate and natural fine aggregate of standard size are utilized after proper sieve analysis, so as to obtain the standard size for both kinds of aggregates. To evaluate the physical properties of aggregates, various tests are conducted such as determination of moisture content, impact value of aggregates, flakiness, and elongation index values of aggregates.

Filler

Stone dust of specific gravity 2.46 is used as filler in the experimental work.

Bitumen

Bitumen of viscosity grade VG-30 is used for the preparation of the sample mix. Bitumen used in the current study was bought from the Government warehouse in Himachal Pradesh, India, Fig. 1. The properties of bitumen are illustrated in Table 1. The behaviour of bitumen mixture depends on bitumen properties, like sensitivity, viscoelasticity, and aging. The bitumen possesses both properties viscosity and elastic behaviour, so it should be taken as a viscoelastic material at pavement temperature.

Table 1. Physical properties of bitumen.

Property	Values
penetration	59 cm
ductility	41 cm
softening point	39 °C
specific gravity	1.049

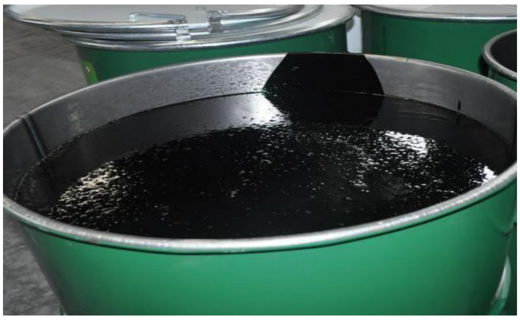

Figure 1. Bitumen used as binder.

Figure 2. Small pieces of sisal fibre used in the present work.

Sisal fibre

Sisal fibre of length 6-8 mm and diameter 0.2-0.6 mm is used in the present study, Fig. 2. The fibre is coated with slow setting emulsion and kept in a heated air stove to increase its durability. Properties of bitumen are given in Tables 2 and 3, respectively.

Table 2. Physical property of sisal fibre.

Property	Value
density	1.49 gm/cm^3
elongation	2.49 %
tensile strength	550 MPa
Young’s modulus	1.99 MPa

Table 3. Chemical property of sisal fibre.

Property	Values (%)
cellulose	71
hemi-cellulose	12
lignin	12
pectin	9
moisture content	20
Ph value	6

RESULTS AND DISCUSSION

We discuss the results and observations of bituminous mixes by different tests. The first part is about optimal bitumen content determination (OBC). The stone dust is used as a filler. Marshal bituminous concrete properties are evaluated with or without reinforcement, and optimal fibre content is carried out from the results. Third part deals with evaluation of bituminous concrete (BC) mixes with and without sisal fibre, by draindown test. In calculations the formula and parameter are taken from ref. /5/.

Determination of optimal bitumen content (OBC)

Marshal stability test is carried out to find optimal moisture content. Two samples are prepared to each bitumen content and values are shown in Table 4. Optimal moisture content value is 5 %, as shown in the results conducted by Marshal Stability Test.

Table 4. Optimal binder content.

Bitumen content	Gmm	Gmb	Va	VMA	VFB	Stability value (kN)	Flow value (mm)
4 %	2.43	2.26	7%	15.58%	55.07%	18.3	2.96
4.50 %	2.413	2.31	4.26%	14.16%	69.91%	23.14	3.25
5 %	2.397	2.32	3.21%	14.24%	77.44%	16	3.54
5.50 %	2.318	2.32	2.56%	14.69%	82.56%	14	3.8
6 %	2.365	2.33	1.48%	14.77%	89.98%	12	4.1

OBC	Stability (kN)	Flow (mm)	VFB	Va	VMA
5 %	16	3.54	77.44 %	3.21 %	14.24 %

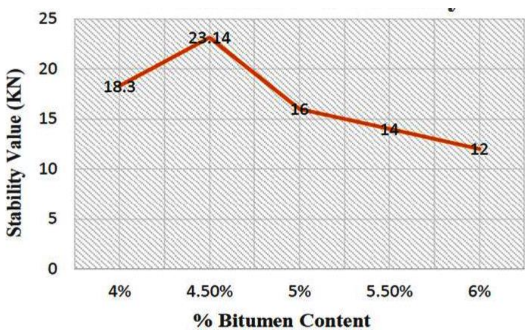

Figure 3. Marshall stability of BC by varying binder content.

Marshall stability

The value of stability increases with increase of binder content to some extent, and then stability decreases. The variation in Marshall stability with different binder contents is shown in Fig. 3.

Flow value

The flow value of bitumen content should lie between 2-4 mm. The change in flow value with varying BC is shown in Fig. 4. It is found that flow value increases as the binder content is increased.

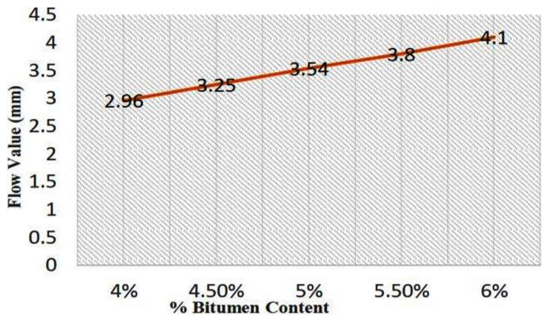

Figure 4. Variation of BC flow value by varying binder proportion.

Air void

From the study it is found that air voids decrease as binder content increases. The air void with varying binder content is shown in Fig. 5. Air void should lie between 3 to 6 % as per MORTH recommendation.

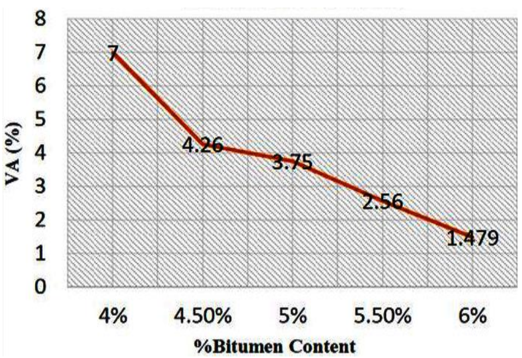

Figure 5. Variation of air void by varying bitumen proportion.

Voids in mineral aggregate (VMA)

VMA with varying binding content is shown in Fig. 6. As shown, it first decreases and then increases at a higher rate.

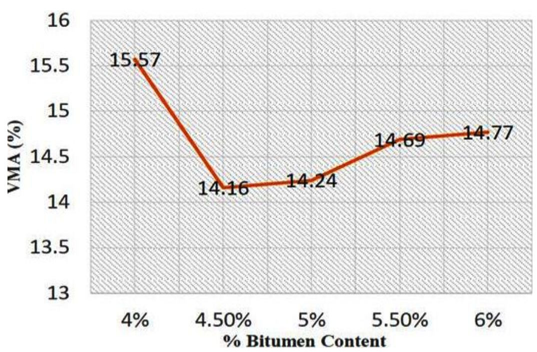

Figure 6. Variation of VMA in BC by varying binder proportion.

Void filled with bitumen (VFB)

With increase in binder content, VFB increases. The difference in VFB content is shown in Fig. 7.

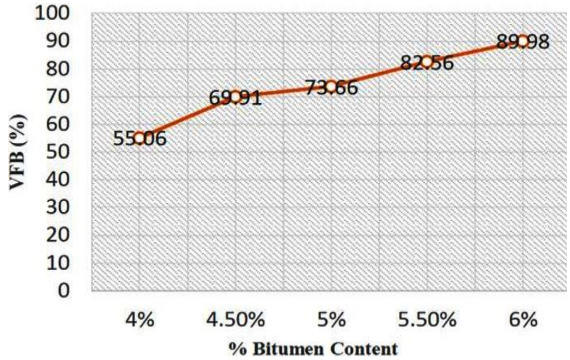

Figure 7. Variation of VFB in BC by varying bitumen proportion.

Determination of optimum fibre content (OFC)

From the results of the Marshal stability test, the binder content is maintained at 5 % and fibre content is kept between 0 to 0.8 % as fibre length is kept between 6-18 mm. The Marshal stability test is conducted corresponding to different fibre content samples and the following results are found as shown in Table 5.

Marshall stability

The characteristics of the Marshall modified mix with sisal fibre are shown in Fig. 8. A design procedure for the Marshall mix was evaluated in this experimental study by modifying BC with sisal fibre. The contents of the bindings varied from 4-6 %. It is found that optimal binder content is 5 %. Fibre content varied percentage in this graphic representation (0.2%, 0.4%, and 0.6% and0.8%) and the length of fibre varied by length (6mm, 10mm, 14mm and 18mm). Stability graphs show stability increase until fibre length of 10 mm and fibre content of 0.4 is reached, but stability decreases when adding more than 0.4 %.

Table 5. Values of Marshal parameters with OBC 5 %.

BC (%) OBC-5% fibre content % (fibre length)	VA	VMA	VFB	Stability	Flow
0.4 %					
6 mm	6.38	17.37	62.79	15.32	3.237
10 mm	5.4	17.67	71.6	15.89	3.11
14 mm	4.6	17.67	74.4	16.54	2.9
18 mm	4.1	17.80	76.8	16.59	2.57
0.6 %					
6 mm	5.4	16.82	65.5	14.2	3.2
10 mm	5.27	17.63	72.5	14.8	3.7
14 mm	4	17.93	67.75	15.55	2.46
18 mm	5.46	17.63	67.5	14.5	3.6
0.8 %					
6 mm	5	17.56	68.12	14.8	3.2
10 mm	5.27	17.69	74.38	14.5	3.6
14 mm	3.97	18	69.25	13.23	2.23
18 mm	4	17.19	68.58	15.2	3.73

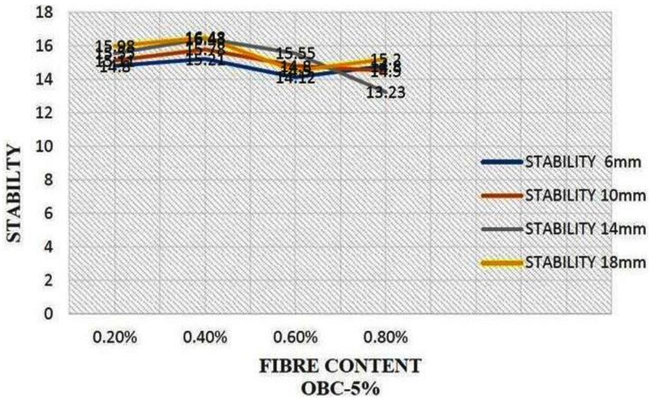

Figure 8. Variation of Marshall stability of BC with different fibre.

Flow value

Up to a certain level, by increasing fibre content and fibre length, reduces the flow value of the sample. For BC, the flow value should be 2-4 mm. A flow value variation with different BC binding content is shown in Fig. 9.

Figure 9. Variation of BC flow by varying fibre content and length.

Air void

According to MORTH recommendation it is specified that value of air voids in sample should lie between 3-6 %. Air vacuum content decreases by increasing binder content. Variation in air content corresponding to different fibre content is shown in Fig. 10.

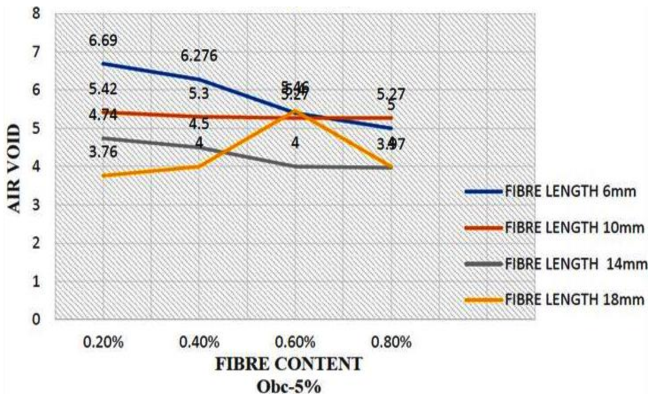

Figure 10. Variation of air void of BC by varying fibre length.

Void filled with bitumen (VFB)

Void filled with bitumen shows a stable and good binding character to an addition of 0.4 %. Variation in the VFB with various fibre content binders is shown in Fig. 11.

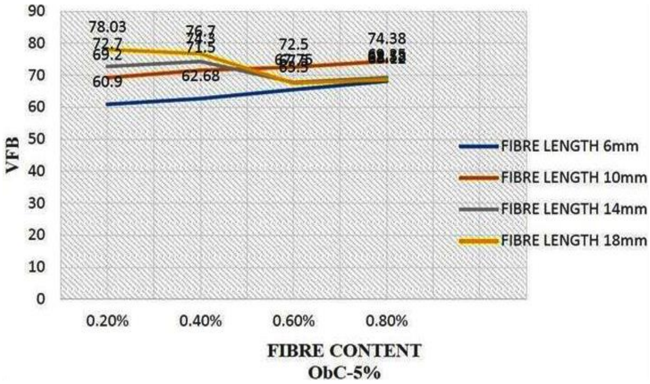

Figure 11. Variation of VFB of BC by varying fibre length.

Void in mineral aggregate (VMA)

Void mineral aggregates with fibre content up to 0.4 % show good results, which increase and decrease gradually. Results are shown in Fig. 12 which depicts the change in VMA with variation in fibre content within the sample.

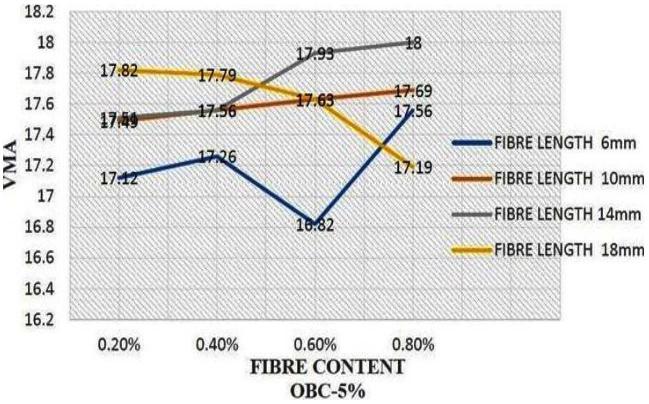

Figure 12. Variation of VMA in BC by varying fibre proportion.

Draindown

Draindown properties for bituminous mixtures prepared to their OBC and OFC, as shown in Table 6, MORTH 2001 specifications, are verified. In this part, the draindown test is discussed as a comparison with and without fibre. Table 6 shows draindown values of the tested samples.

Table 6. Draindown values of mix.

Bitumen mixes	Draindown (sample 1)	Draindown (sample 2)
without fibre (OBC- 5%)	0.2	0.3
with fibre (OBC-5% OFC- 0.4%)	0.2	0.2

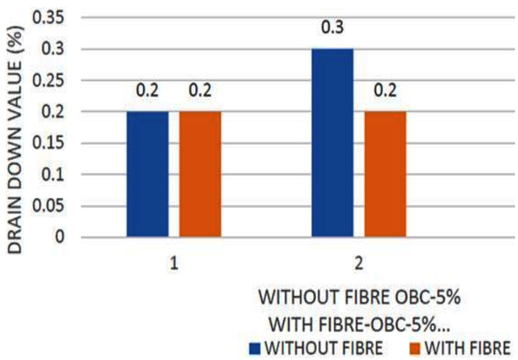

Figure 13. Variation of draindown value.

Draindown mix (without fibre)

Draindown tests are conducted on plain bituminous sample and results are shown in Table 6. Drainage of plain bituminous concrete is found to be high as compared to the reinforced sample.

Draindown mix (with fibre)

Draindown tests are conducted on mixed sample (with fibre) and drainage of bituminous concrete without fibre is observed which becomes stable or reduced.

CONCLUSION

Based on experimental research results and the discussion conducted on mixes, i.e., the conclusion is drawn for BC with natural fibre (sisal fibre).

It is observed that after adding sisal fibre to 0.4 % and fibre length 10 mm and bitumen content 5 %, the stability of the mix increases, but when adding more than 0.4 % fibre content, stability starts to decrease.

The increase in fibre contents up to 0.4 % and fibre length 10 mm and bitumen content 5 %, has shown a decrease in air void and flow value. Thus, the consistency of asphalt changes and becomes difficult.

After adding the sisal fibre coated with SS-1 emulsion, draindown property of the mix decreases which demonstrates good bitumen characteristics.

It is concluded from the results that by adding the sisal fibre in the sample, the viscosity and density increases as compared to the plain sample, as depicted by ultrasonic pulse velocity test.

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