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STUDY INTO THE DRAIN DOWN CHARACTERISTIC OF SMA CONCRETE USING SANDSTONE AS MINERAL FILLER

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ABSTRACT

One of the component ingredients in SMA mixtures is mineral filler occupying about 8-10% of asphalt pavement materials (by weight of aggregate). Different types of mineral fillers are used in the SMA mixes such as stone dust, ordinary Portland cement (OPC), slag cement, fly Ash, hydrated lime etc. In this study, sandstone was used as mineral filler and various experimental investigations were carried out to determine its usage as mineral filler in SMA mixes in comparison to the conventional (granite) filler. Marshall Stability and flow analysis as well as density and void analysis were carried out on both samples which yielded an Optimum Binder Content of 5.92% and 6.02% for samples with granite and sandstone filler respectively. Other performance tests were conducted, and the Marshall Stability and flow value determined at OBC are 8.07 kN and 4.4 mm respectively for mixes with granite filler, while 7.58 KN and 4.9 mm was recorded for mixes with sandstone filler. Air voids obtained for both mixes was higher than the specified value of 4% at OBC. Draindown characteristics of both mixes were determined to be 0.24% and 3.3% for mixes with granite and sandstone filler respectively. Indirect Tensile Strength Test was conducted on the samples and SMA with granite filler gave higher strength at lower temperature than SMA with sandstone filler. Therefore, sandstone dusts as mineral filler produces SMA with Higher Draindown characteristics which consequently result in the reduction of the tensile strength of SMA.

Keywords: Asphalt Pavement, Stone Dust, Marshal Stability, Granite Filler, Tensile Strength.

INTRODUCTION

Stone Mastic Asphalt (SMA) is a stone-to-stone matrix structure arrangement which provides resistant to mechanical and temperature deformation, rutting, cracking and weathering under heavy wheel load. It was earlier developed in Germany in the mid 1960's which later spread across Europe and different part of the world in 1980's and 1990's. SMA becomes very popular and however many different research have been undertaken to ascertain the performances of locally available waste material in the SMA mix.

Stone Matrix Asphalt (SMA) is a superior type of Hot Mix Asphalt pavement. One of the component ingredients in SMA mixtures is mineral filler occupying about 8-10% of asphalt pavement materials (by weight of aggregate). Mineral fillers combine with the asphalt, fibres, and a small percentage of fine aggregate particles to produce binder rich mastic which fills the void spaces between the coarse aggregate skeleton. The requirements for mineral filler are not complex. A variety of materials have been used as mineral fillers in SMA mixtures including rock dust, products of various mineralogy, fly ash, Portland cement, kiln dusts, and limestone. As defined in most of the road standard, mineral fillers are considered part of the aggregate and are partially defined as consisting of finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, loess, or other suitable mineral matter. Fillers play an important role in stabilizing the Hot Mix Asphalt (HMA) by filling the voids within the larger aggregate particles, and improving the consistency of the binder that cements the larger aggregate particles.

In recent years, many studies have been carried out on the use of construction and demolition (C&D) wastes in developed countries. The most considerable interest is the reuse of waste materials in new construction sectors (Xue et al. 2009). Reusing waste material is one of the many ways to solve the problem of excess solid waste materials in industrial and urban areas. It can make significant contributions to the environment and the economy, such as (1) reducing the overuse of natural resources and saving them from exhaustion, (2) reducing the environmental pollution levels from waste materials generated in urban and industrial areas, and (3) contributing to savings in energy and money (Fontes et al. 2010).

Furthermore, mineral filler affect the workability, moisture sensitivity, stiffness, and aging characteristics of HMA (Mogawer and Stuart, 1996). The effect of fillers is more prominent in gap-graded asphalt mixtures, such as the Stone Matrix Asphalt (SMA) mixture that contains large amounts of coarse aggregate. Typical, filler completely passes through 0.60 mm (No.30) sieve, with at least 65-70 percent by weight of the particles passing the 0.075 mm (No.200) sieve.

Draindown is considered to be that portion of the mixture (fines and bitumen) that separates itself from the sample as a whole and flows downward through the mixture NAPA (1999). Irregular distribution of bitumen binder due to its drain down can lead to ravelling of zones with low bitumen binder content and reduction of permeability in zones with accumulation of bitumen binder according to Kumar et al. (2007) and Kamaraj et al, (2006). Potential problems with SMA mixtures are drainage and bleeding. Storage and placement temperatures cannot be lowered to control these problems due to the difficulty in obtaining the required compaction. Therefore, stabilizing additives has been added to stiffen the stone mastic and thereby reducing the drainage of the mixture at high temperatures and to obtain even higher binder contents for increased durability Kamaraj et al (2006). *Mohammad et al*. (2012) studied the SMA performances using three different aggregates and reported that sandstone produces the least permanent deformation which is the most important factor for rutting resistance. It was also concluded that SMA production with lime stone is least desirable due to its high permanent deformation. *Marco Pasetto* and *Nicola Baldo* (2012) studied the effect of SMA using steel slag as aggregates and found out that it effectively satisfies the requisites for acceptance in the road sector technical standards. It also showed higher mechanical characteristics than those of the corresponding asphalts with full natural aggregate.

Y. F. Qiu and K. M. Lum (2006) found that aggregate gradation is an important factor which helps in better understanding of its effect on the load-carrying capacity of an asphalt mixture basically the stone matrix asphalt (SMA). In was also reported in their research that the coarse aggregate stone-to-stone contact was developed when the volume of coarse aggregate was in the range of 95–105% of the rodded unit weight. The test results indicated that the SMA mixtures having better stone-to-stone contact exhibited excellent rutting characteristics which are essential characteristics of aggregate gradation.

Karasahin and Terzi (2007) used marble dust obtained from shaping process of marble blocks and lime stone as filler material in asphalt concrete mixes and optimum bitumen content was determined by Marshall Test and it showed good result. The Marshall and plastic deformation tests showed that limestone dust and marble dust gave almost the same results. Marble dust had higher values of plastic deformation and hence was suggested for low traffic volume roads.

Yongjie Xue et al, (2009) utilized municipal solid waste incinerator (MSWI) fly ash as a partial replacement of fine aggregate or mineral filler in Stone Matrix Asphalt mixtures. They made a comparative study of the performance of the design mixes using Super pave and Marshall Mix design procedures. *Jony et al*, (2011) studied effect of using waste glass powder as mineral filler on Marshall property of SMA by comparing with SMA where lime stone, ordinary Portland cement was taken as filler with varying content (4-7%), mineral filler occupies a good portion in the SMA mixes hence they do affect the quality of SMA mixes, therefore it becomes essential to study the effect of fillers in SMA.

In this research, we have studied the drain down characteristics of stone mastic asphalt concrete prepared at optimum binder content. Also we checked the suitability of replacing the conventional mineral filler in SMA mixes. The significance of this research is to encourage the use of locally available material waste products from local industries as components of pavement structure. The incorporation of sandstone dust as a component of SMA concrete will reduce the cost of transporting materials from longer proximities which consequently reduces construction expenses and discourages environmental disposal of waste materials leading to landfill and land pollution.

MATERIALS AND METHODOLOGY

MATERIALS

Materials used in this study include:

Aggregates

The aggregates used in this research work for SMA mixes are as per the requirement specified in the IRC SP79 – 2008. The various types of aggregate used are presented below;

Coarse Aggregates

The coarse aggregate used consist of crushed rock retained on 2.36 mm sieve which was obtained locally within Jodhpur city, India. The physical requirement of the coarse aggregate was adopted base on the specification of the IRC SP: 79-2008. The physical requirements of aggregates are presented in table 1 while properties of aggregates used in this research are presented in table 2.

Fine Aggregates

The fine aggregate consists of crushed stone dusts collected from a local crusher with fractions passing 2.36 mm and retained on 0.075 mm IS sieve. The fine aggregate is clean, hard, durable and free from soft pieces, organic or deleterious substances as specified in IRC:SP:79-2008

Mineral Filler

The aggregate passing 0.075 mm IS sieve is called mineral filler. However, two different filler materials were used i.e. sandstone dust and the conventional granite stone dust, which serves as a benchmark for the comparison.

Table 1: Physical requirement of coarse aggregate for Stone Mastic Asphalt (SMA)

Property	Test	Method	Specification
Cleanliness	Grain size analysis	IS:2386(P-1)	<2% passing 0.075 mm sieve
Particle Shape	Combined Flakiness and Elongation Index	IS:2386(P-1)	<30%
Strength	Loss Angeles Abrasion Value	IS:2386(P-1)	<25%
	Aggregate Impact Value	IS:2386(P-1)	<18%
Polishing	Polished stone Value	IS:2386(P-1)	>55%
Soundness	Soundness (either Sodium or magnesium)		
	Sodium sulphate	IS:2386(P-1)	<12%
	Magnesium sulphate	IS:2386(P-1)	<18%
Water absorption	Water absorption	IS:2386(P-1)	<2%

Table 2: Physical Properties of Aggregate

Property	Granite	Sandstones
Aggregate Impact Value (AIV) (%)	14.30	19.20
Aggregate Crushing Value (ACV) (%)	13.00	16.40
Los Angeles Abrasion Value (LAV) (%)	18.00	22.60
Flakiness Index (FI) (%)	18.83	23.20
Elongation Index (EI) (%)	21.50	23.40
Water Absorption (WA) (%)	0.50	1.60

Bituminous Binder

Viscosity Grade bitumen (VG-30) was used as bituminous binder for this research work, which is in compliance with the Indian Road Congress Manual specification for paving bitumen BIS: 73 and IRC:SP:53. Specifications and design requirements for SMA Mix are presented in table 3 below;

Table 2: SMA Mix Design Requirements

Mix design Parameter	**Requirement**
Air void content (%)	4.0
Bitumen Content, (%)	5.8 min
Celluloid fibres	0.3% minimum by weight of total mix
Voids in mineral aggregate (VMA), (%)	17 min
VCA mix, (%)	Less than VCA (dry Rodded)
Asphalt drain down, (%) AASHTO T305	0.3 max
Tensile Strength Ratio (TSR), (%) AASHTO T283	85 min

METHODOLOGY

In other to accomplish the stated aim and objectives of the research, the investigation was carried out in two (2) stages. The first stage is related to the experiments on the physical properties of the materials to ascertain its suitability and conformity with the requirement for use as given in the Tentative Specification for Stone Mastic Asphalt, IRC SP: 79-2008 and MORTH Specification. The second stage consists of experiments carried out on the SMA Marshall Samples with two different filler material to determine its performance.

Marshall Mix Design

This test procedure was used in designing and evaluating the bituminous paving mixes and Stone Mastic Asphalt (SMA), because it has been the most extensive routine test conducted for paving jobs. The two major features of the Marshall method of designing mixes are density-void analysis and stability-flow analysis.

Marshall Sample preparation

Approximately 1200 g of aggregates and filler was heated to a temperature of 160°C to 170°C. Bitumen was heated to a temperature of 160°C with the first trial percentage of bitumen. Then the heated aggregates and bitumen are thoroughly mixed at a temperature of 160°C to 170°C. The mix was placed in a preheated mould and compacted by hammer having a weight of 4.5 kg and a free fall of height 457 mm giving 50 blows on either side at a temperature of 160°C. For the proposed design mix gradation, three specimens were prepared for each of bitumen content within the range of 5.5% to 7.5% at increments of 0.5 percent in accordance with ASTM D 1559 using 50 blows/face compaction standards.

Density (Specific Gravity) and Void Analysis

The various parameters used in this analysis include; (i) Theoretical Maximum Specific Gravity G_{mm}, (ii) The Bulk Specific Gravity of the mix G_{mb}, (iii) Percentage Air Voids VA, (iv) Percentage volume of Bitumen V_b, (v) Percentage Void in Mineral Aggregate VMA and (vi) Percentage Voids Filled with Bitumen VFB. As soon as the freshly compacted specimens have cooled to room temperature, the bulk specific gravity of each test specimen was determined in accordance with ASTM D 2726. Specific gravity and voids analysis were carried out for each test. The various mathematical relationship for calculating the above listed parameters where presented below.

i. **Theoretical Maximum Specific Gravity G_{mm}**

$$G_{mm} = \frac{W_{mix}}{\text{Vol of the (mix} - \text{air voids)}}$$

Where, W_{mix} is the weight of the bituminous mix, G_{mm} is calculated as per ASTM D 2041-95.

ii. **The Bulk Specific Gravity of the mix** G_{mb}

$$G_{mb} = \frac{W_{mix}}{\text{Bulk Volume of the mix}}$$

The bulk specific gravity of the mix is the specific gravity considering air voids

iii. **Percentage Air Voids VA**

$$VA = \left(\frac{G_{mm} - G_{mb}}{G_{mm}}\right) \times 100$$

iv. **Percentage volume of Bitumen V_b,**

$$V_b = VFB + V_{ab}$$

Where, VFB is the volume filled with bitumen in the mix and V_{ab} is the volume of the absorbed bitumen which has been absorbed into the pore structure of the aggregate.

v. **Percentage Void in Mineral Aggregate VMA**

$$VMA = \left(1 - \frac{G_{mb}P_s}{G_{sb}}\right) \times 100$$

Where, P_s is the fraction of aggregate presents, by total is weight of the mix and G_{sb} is the bulk specific gravity of the mixed aggregate.

vi. **Percentage Voids Filled with Bitumen VFB.**

$$VFB = \frac{(VMA - VA)}{VMA} \times 100$$

Marshall Stability and Flow

The stability and flow value of each test specimen were determined in accordance with ASTM D 1559. The heights of the samples were measured and specimens were immersed in a water bath at 60°C for 35±5 minutes. Samples were removed from the water bath and placed immediately in the Marshall loading head. The load is applied to the specimen at a deformation rate of 50.8 mm/minute. **Stability** is measured as the maximum load sustained by the sample before failure. **Flow** is the deformation at the maximum load. The stability values are then adjusted with respect to the sample height (stability corrections).

Determination of Optimum Binder Content (OBC)

The average values of Stability, Flow, Density, VA, VMA and VFB obtained are plotted separately against the bitumen content and graphs were plotted. The average of the binder content corresponding to maximum stability, flow value at mid of 4-6 mm (5 mm), maximum density, and Air Void at 4% is calculated as the optimum binder content.

Draindown Test

Several methods have been used to evaluate the drain-down characteristics of bituminous mixtures. A minimum of three samples were used for the test procedure. The weight of an empty wire basket was determined and about 1200 g of fresh hot asphalt samples was placed loosely and the weighed. The weight of the plate to be placed under the wire basket was also determined to the nearest 0.1 g, the basket was hung in the oven and the catch plate was placed beneath the wire basket for about 1 hour ± 5 minutes.

The basket and the catch plate were removed from the oven and allowed to cool to ambient room temperature. The weight of the catch plate + the drain material was determined to the nearest 0.1 g.

The percentage of the drained mixture was calculated from the formula;

$$Draindown(\%) = \left(\frac{D - C}{B - A}\right) \times 100$$

Where; A is the mass of the empty wire basket in g (gram), B is the mass of the wire basket plus sample in g, C is the mass of the empty catch plate in g and D is the mass of the catch plate plus drained material in g.

ANALYSIS AND DISCUSSION OF RESULTS

MARSHALL PROPERTIES

The results of the experiments conducted are presented and discussed below.

Marshall Stability

Table 4 represents the stability value with respect to binder content for samples with different filler materials. The maximum stability recorded for granite filler material (stone dust) was 8.04 KN corresponding to a binder content of 6.0%. While the maximum stability observed for samples with sandstone filler was 7.90 KN at the same binder content of 6.0% as shown in figure 1 below.

Table 4: Marshall Stability for samples with granite and sandstone filler

	STABILITY VALUE (KN)	
BINDER (%)	GRANITE	SANDSTONE
4.0	6.50	6.35
4.5	7.04	6.85
5.0	7.65	7.24
5.5	8.00	7.84
6.0	8.04	7.90
6.5	7.46	7.10
7	6.54	6.12

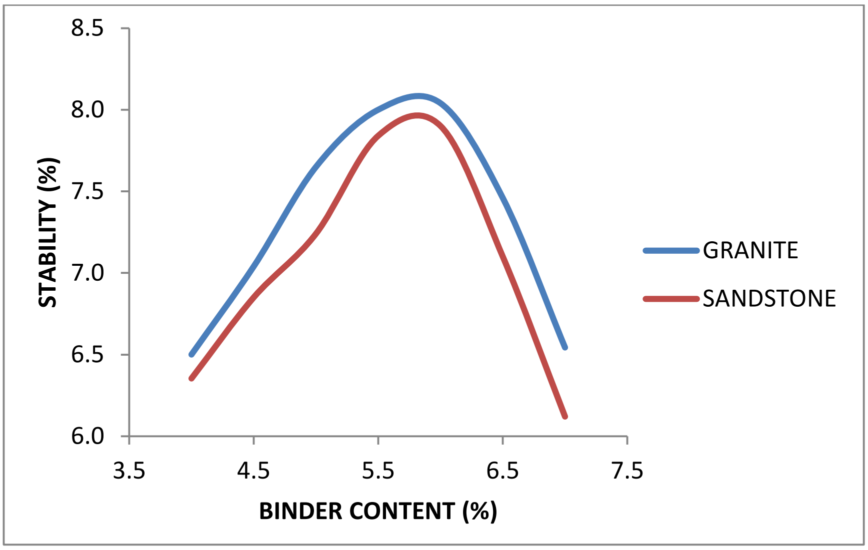

Fig. 1: variation of stability value for samples with granite and sandstone filler

Figure 1 shows the variation of stability value with binder content for the samples with granite filler (stone dust) and sandstone mineral filler. It can be observed that the stability values increases with the hardness of the binder to a maximum value after which it decreases in strength as a result of excess binder content. Also, it can be observed that the stability of the samples prepared using the granite samples (stone dust) is a higher than stability value of samples with sandstone filler. This is probably because of the low quality of the parent rock (sedimentary) having low specific gravity and high water absorption. Similar findings were reported in related research conducted by *Jony et al,* (2011).

Flow Value

The results of the flow value observed during the Marshall test for samples with different filler materials were presented in table 5 below.

Table 5: Flow Value for granite and sandstone filler

FLOW VALUE (mm)		
BINDER (%)	GRANITE FILLER	SANDSTONE FILLER
4.0	2.17	1.92
4.5	2.43	2.20
5.0	2.93	2.77
5.5	3.67	3.43
6.0	4.90	4.40
6.5	5.57	5.27
7.0	6.07	5.80

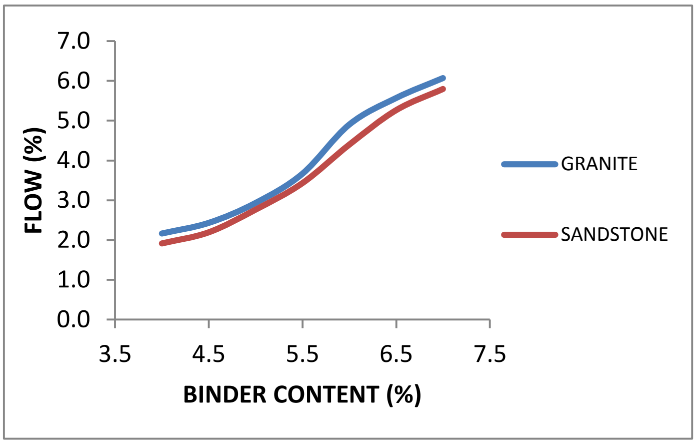

Fig. 2: variation of flow value of granite and sandstone filler with binder content

The variation of flow value with binder content for granite (stone dust) and sandstone dust was shown in figure 2. It was observed that the flow value increases with increase in binder content as per normal trend. Also, it can be seen clearly from the figure that flow value of Marshall Samples with sandstone filler is low than that of granite filler. This is as a result of the presence of more fines in the mix. The sandstone mineral filler possess almost 95% fines passing 75 micron IS sieve sizes. This behaviour of the material agrees with the work of *Mohammad et al.* (2012), where he studied the SMA performances using three different aggregates and found out that sandstone produces the least permanent deformation which is the most important factor for rutting resistance. Hence, deformation of the samples will be more on samples containing more fines than samples with fewer fines.

Density

The densities obtained at different binder content for SMA sample with granite and sandstone mineral filler were presented in table 6

Table 6: Density of samples with Granite and Sandstone filler

DENSITY (g/cm^3)		
BINDER (%)	GRANITE	SANDSTONE
4.0	2.115	2.011
4.5	2.130	2.024
5.0	2.150	2.056
5.5	2.215	2.096
6.0	2.334	2.201
6.5	2.286	2.189
7.0	2.239	2.156

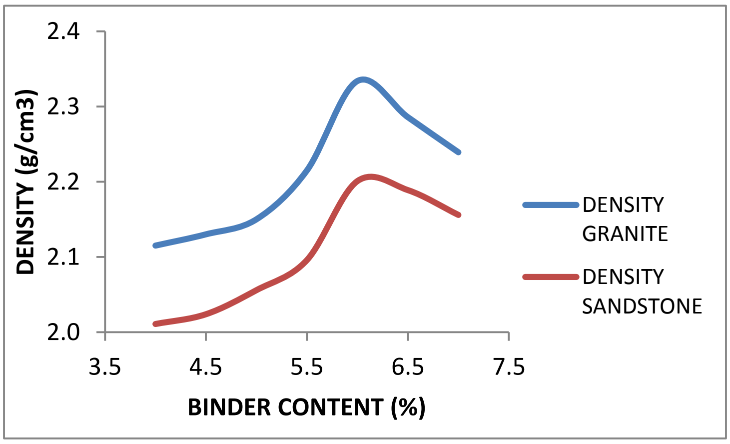

Fig. 3: variation of density of samples with granite and sandstone filler

Figure 3 shows the variation of density of the samples with respect to binder content. From figure 3, it is seen that the graph follows the normal trend. The density of the two samples increases to a certain value and then decrease. It is also observed that the density of samples with granite filler have higher density values compared to sandstone dust. This is because the quality of the sandstone is low having a higher water absorption value which indicates high porosity. This behaviour of material was also found in related research findings reported by Karasahin and Terzi (2007).

Per cent Air Void

The results of the air void computed for mineral fillers at corresponding binder content were presented in table 7.

Table 7: per cent air void of samples with granite and sandstone filler

AIR VOIDS (%)		
BINDER (%)	GRANITE	SANDSTONE
4.0	8.232	10.021
4.5	7.612	9.654
5.0	6.541	8.126
5.5	5.122	6.987
6.0	3.964	4.632
6.5	2.440	2.941
7.0	0.385	1.938

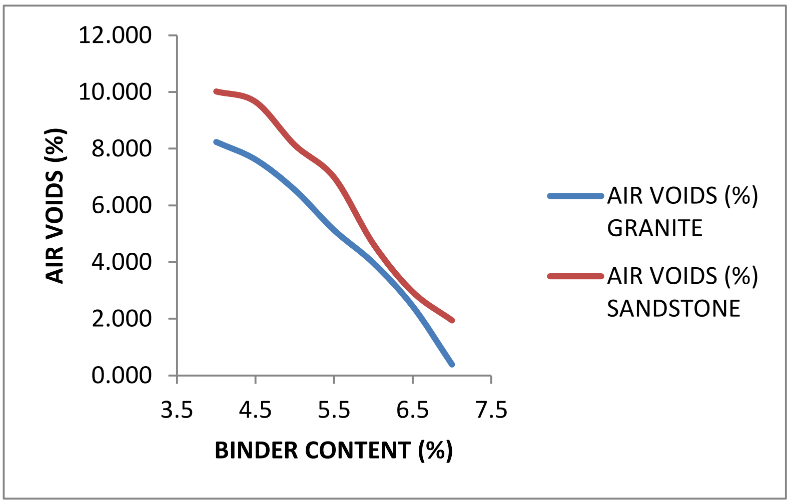

Fig. 4: variation in air voids of samples with granite and sandstone filler

Figure 4 shows the variation of air void in the mix with binder content for different filler material i.e. granite and sandstone filler. It is observed that sandstones give higher percentage of air voids than granite filler (stone dust). This may be due to the fineness of the sandstone dust which tends to drain off the mix. However, excessive air voids as indicates by samples with sandstone would result in cracking due to insufficient bitumen binders to coat on the aggregate. This is in accordance with the work of Kumar et al. (2007) and that of Bindu C.S and Beena K.S. (2014), where similar findings were reported.

Voids Filled with Bitumen (VFB)

Void filled with bitumen VFB is defined as the portion of the volume of void space between the aggregates particles that is occupied by bitumen. Results from figure 5 showed that sample with granite filler gave higher value of VFB than sample with sandstone. The results obtained at various binder content conformed to the Indian Road Congress Manual specification for paving bitumen BIS: 73 and IRC: SP: 53.

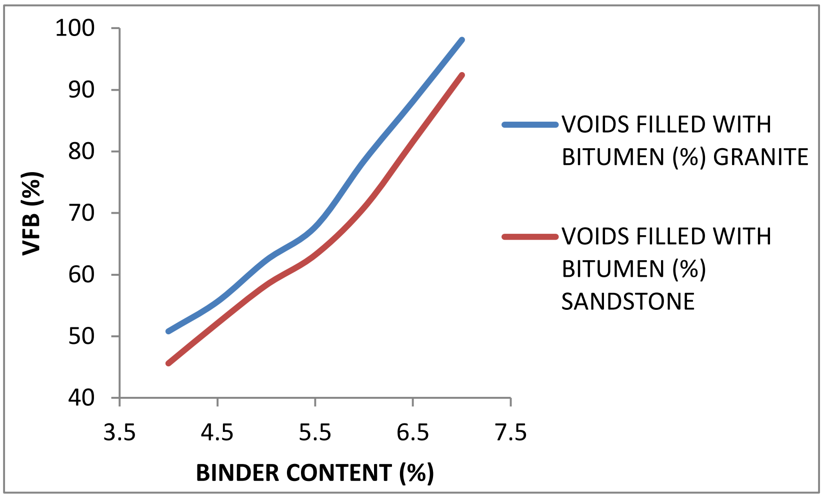

Figure 5: variation of VFB for samples with granite and sandstone filler

Optimum Binder Content

The Optimum Bitumen Content (OBC) for the SMA mixture with different filler was determined to be 5.92% and 6.03% (by weight of total mix) for mixtures with granite filler and sandstone filler respectively as shown in table 8 below. Each optimum binder content (OBC) determined conforms to the specified value of binder content for used in SMA mixtures which is 5.8 minimum.

Table 8: Optimum Binder Content

OPTIMUM BINDER CONTENT (%)		
	Granite Filler	Sandstone Filler
Max. Stability	6.00	6.00
Flow Value at 5mm	5.63	5.79
Max Density KN/mm^2	6.00	6.00
Air Voids at 4%	5.98	6.19
VFB at 70%	5.98	6.19
AVERAGE	5.92	6.03

Marshall Properties at OBC

The Marshall properties which include; Marshall Stability, Marshal flow, density, air voids, VMA and VFB of the SMA samples at OBC where determined and presented in table 9 below:

Table 9: Marshall Properties of SMA samples at OBC

	GRANITE FILLER	SANDSTONE FILLER
STABILITY (KN)	8.07	7.58
FLOW VALUE (mm)	4.9	4.4
DENSITY (g/cm^3)	2.252	2.201
AIR VOID (%)	4.11	4.802
VMA (%)	17.3	19.7
VFB (%)	53.1	75.7

Draindown

Table 10 presents the result of the draindown performance of the SMA mixes. Draindown characteristic is an important indicator of the amount of bitumen which can be separated from the mix during transportation from the asphalt plant to the construction site.

Table 10: Draindown of SMA Samples

Type of filler	Draindown (%)	Average (%)
Granite (Stone Dust)	0.26	0.24
	0.25	
	0.21	
Sandstone Dust	0.32	0.33
	0.41	
	0.25	

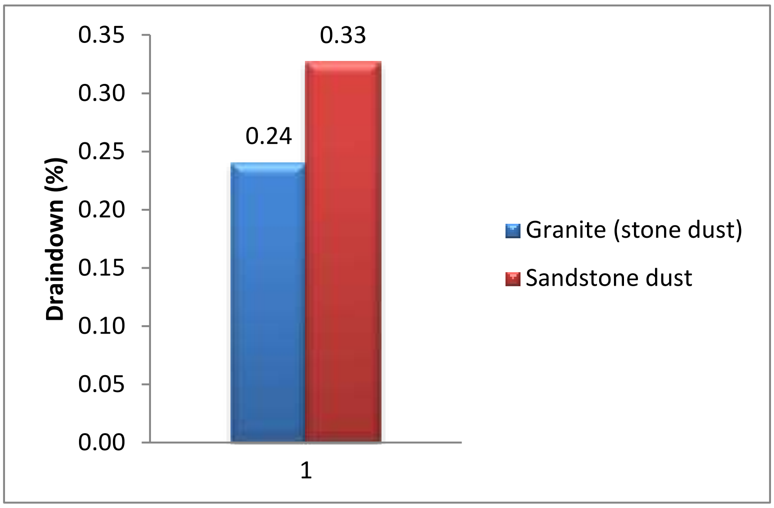

Fig. 6: Draindown characteristics of SMA samples

Figure 6 shows the draindown characteristics of the SMA samples for samples with granite and sandstone filler respectively. It can be observed that the draindown characteristic of samples with sandstone was 0.33%, while samples with granite samples have a draindown of 0.24%. This clearly indicates that samples prepared using sandstone as filler is likely to drain more as compared to mixes with granite filler. However, for both SMA mixes, high values of draindown were observed. This may be due to the absence of fibre material in both mixes; since the function of fibre in a mix reduce draindown characteristics of the SMA Mix. Also, it can been seen that draindown characteristics of SMA mixes with sandstone as filler material has exceeded the specified limit of 0.3% as given in table 3. This behaviour agrees with the research work Bindu C.S and Beena K.S. (2014), as similar finding was reported.

CONCLUSION

Based on the results and discussions of experimental investigations carried out on different SMA mixes, the following conclusions were drawn;

It was observed that with increase in binder content, the Marshall Stability value increases to a certain binder content and then decreases for both SMA mixes. Moreover, the stability value of SMA specimen with granite filler was found to have higher value of 8.07 KN as compared to SMA samples with sandstone filler with 7.58 KN stability value at OBC. The flow value increases with increase in binder content and decreases with increase in stiffness of the binder. Also the SMA samples with granite filler recorded a lesser flow of 4.4 mm than samples with sandstone filler having flow value of 4.9 mm at OBC. Thus, SMA with sandstone filler produces asphalt with higher deformation at higher loadings.

The density increases with increase in binder content to a certain binder content after which it decreases. SMA with sandstone filler has less maximum density at OBC as compared to SMA with granite filler. Also, the amount of air voids decreases with increase in binder content in the mix. SMA with sandstone filler contains higher percentage of air voids than SMA with granite filler. These mixes were seen to show higher air voids than specified value of 4% at OBC. However, Optimum Binder Content (OBC) of the SMA mixes with sandstone filler was found to be 6.02% which is higher

than SMA mixes with granite filler with 5.92%. Hence, SMA with sandstone filler will require more bitumen binder than SMA with granite filler. The draindown characteristics of the SMA mixes with sandstone filler was observed to have a value of 0.33% and SMA with granite was observed to have 0.24%. Higher values of draindown were observed due to absence of fibre in the mixes.
Cement and stone dust are the conventional fillers, however sandstone dust can be utilised in place of them, thus, significantly exploiting the spaces consumed by disposing the industrial wastes as landfills.

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