INFLUENCE OF COMPACTIVE EFFORT ON SULFUR MODIFIED SAND - BITUMINOUS PAVING MIXES

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ABSTRACT

The rapid development of road network and many other infrastructure projects has led to a severe depletion in the reserve of available natural stone resources. While in many places in India, the good quality aggregates, especially coarse aggregates are costly and are in short supply; the sand is cheaply and abundantly available in such places. Keeping the fast depleting aggregate resources in mind, the researches on exploring an alternative material such as sand as a substitute for stone aggregates in bituminous paving mixes are worth taking up, even though few earlier studies show not so promising results in respect of sand-bitumen mix.

This work presents an approach to use sand-bitumen mix by modification with sulfur. This paper specifically addresses the influence of compactive effort on performance characteristics of the sand-sulfur-bitumen (S-S-B) paving mixtures. A S-S-B mix comprising of poorly graded river sand, sulfur and VG 30 bitumen with the proportion of 85:10:5 by weight is selected for this study. The test results show that the Marshall stability increases initially and then decreases with the increasing compaction effort applied in the form of number of compaction blows during Marshall specimen preparation. The air voids of the mix are found to decrease with the compaction level initially and thereafter remain more or less constant. It is concluded that a compaction level of 50 blows on each face of the sample is optimum as the improvement in Marshall characteristics beyond this compaction level is marginal.

KEY WORDS: Sand-sulfur-bitumen mix, Marshall Characteristics, Compaction Level

INTRODUCTION

Bituminous pavements are widely used in building a highly expanding transportation network in which aggregates are used as the primary constituent with bitumen serving as a secondary constituent for the purpose of binding the aggregates and making the mix stiff to resist the stresses due to the wheel loads. The economic growth of the country heightens the urban expansion and infrastructure development, which in turn have successively increased the demand for stone aggregates. The uncontrolled extraction of construction aggregates has resulted in a severe depletion of existing natural stone reserves. Thus, the growing shortage in the supply of good quality aggregates, especially coarse aggregates, along with the long-distance expensive hauling of road materials in certain areas has substantially increased the construction cost of bituminous pavement. Moreover, for dense graded mix, the aggregates need to be crushed to different sizes in order to use it in road construction, which is a very difficult and costly process. Besides, at many places, large scale quarrying destroys the geological and ecological balance. Hence, there is a necessity to search for an alternative to coarse aggregates for the construction activities at a reasonable cost. In this direction, serious efforts to utilize the alternate/ locally available materials such as sand in bituminous paving mixes have been underway.

In 1963, a sand-bitumen-sulfur paving material called "Thermopave" was developed by Shell Canada Ltd. The material was reported to possess properties comparable to conventional bituminous mixes (*1*). This made the abundantly available inexpensive sand to be used as a possible alternative to good quality coarse aggregates. Besides, the increase in sulfur supplies due to tighter air-quality controls made the utilization of sulfur in bituminous pavements much more viable. Study showed that the addition of sulfur to bituminous mix, not only improved the mix workability but was also reported to show improved field performance (*2*). Moreover, paving mixes were prepared using a variety of aggregates ranging from fine, one-sized sand to coarse gravels, to explore the range of aggregate gradations potentially suitable for processing with sulfur (*3*). Later, investigation further established that there is a huge potential to utilize sulfur for enhancing the performance of paving material prepared using low-grade aggregates that are otherwise considered unacceptable for construction purposes (*4*). A study by Shane and Burgess revealed that the Thermopave mix could be laid with no compaction at all (*5*); while another showed that it is sufficient to apply as few as two blows on only one face of the specimen (*6*). Further research presented that 10 blows of compaction on each face of the specimen were sufficient for sand-sulfur-bitumen mixes. However, an optimum value of Marshall stability was found to be obtained at 40 blows of compaction (*7*). Although it was claimed that satisfactory pavements were obtained with lower level of compaction, but it resulted in a mix having high air voids and low unit weight which might not be suitable for paving purposes. Hence, to achieve the best performance quality of the sand-sulfur-bitumen mix, an investigation was directed towards optimizing the number of blows needed for such a mix.

EXPERIMENTAL INVESTIGATIONS

Materials Used

The paving material under study was comprised of a mixture of sand, sulfur, bitumen. The sand was collected from the nearby Koel river bed of Odisha in India. As per sieve analysis (Figure 1) it was found to be almost uniformly graded with a uniformity coefficient of 2.48 and it has a specific gravity of 2.61.

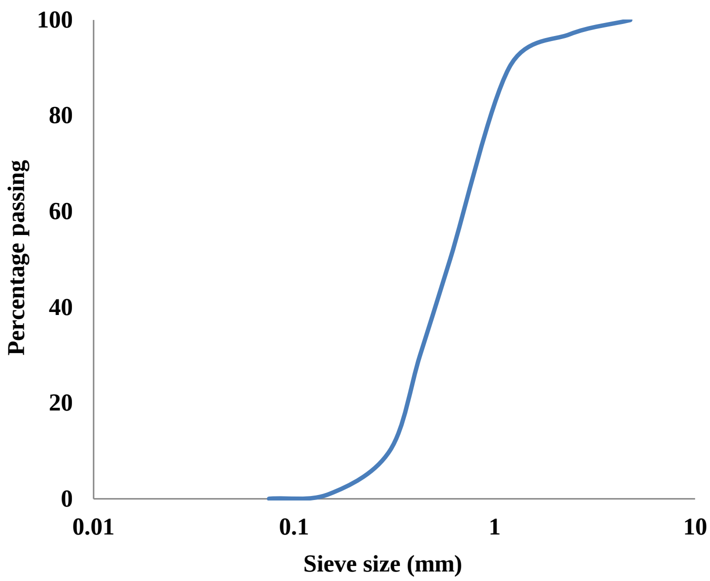

FIGURE 1 Gradation of river sand used

VG 30 bitumen that was collected from local govt. depot, was used as a binder. It was noted to have a specific gravity of 1.01 and softening point (R&B) of 48ºC. The sulfur was of commercial grade, having a specific gravity of 2.095 and melting point of 116.5ºC. The physical properties of materials used are given in Table 1.

TABLE 1 Physical Properties of the Materials Used

Material	Physical Properties	
River Sand	Specific Gravity Coefficient of uniformity Coefficient of curvature	2.61 2.48 0.81
Bitumen	Grade Specific Gravity Penetration at 25ºC (0.1 mm, 5 sec) Softening Point (R&B) (ºC) Ductility (cm) Absolute viscosity at 60ºC (Poise) Kinematic viscosity at 135ºC (cSt)	VG 30 1.01 67 48 100+ 2505 405
Sulfur	Specific Gravity Melting Point (ºC)	2.095 116.5

Methodology

Based on some earlier studies (*7 and 8*), the proportion of sand-sulfur-bitumen mix (by weight) was maintained at 85:10:5 respectively. The three ingredients of the mix, *i.e.*, sand, sulfur and bitumen were mixed in accordance with the optimum mix parameters, presented in a previous study (*8*). For preparation of the mix, measured amount of sand was taken in a bowl and heated to 150ºC like normal aggregates. Sulfur heated separately to 140ºC was added and mixed with the heated sand for about 1 minute 30 seconds. Then bitumen (heated to 140ºC) was added to the sand-sulfur mix and the ingredients were thoroughly mixed for about 2 minutes. The mix temperature was maintained at 150ºC. Marshall specimens of S-S-B mixes were prepared with different levels of compaction achieved by varying the number of blows from 10 to 75; 10, 25, 40, 50, 60 or 75 blows were given on each face. For each mix type, three replicate test specimens, *i.e.*, a total of 18 specimens (6 mixes x 3 replicates) were considered sufficient to provide reliable data. The mix performance in this study has been based on Marshall tests conducted as per ASTM D 1559 (1989) (*9*).

TEST RESULTS AND DISCUSSIONS

Marshall Stability

The Marshall characteristics of the bituminous mixes were studied for different levels of compaction by applying 10, 25, 40, 50, 60 or 75 blows on each face of the sample. The influence of compactive effort as revealed by the effect on Marshall stability values of the mixture is illustrated in Figure 2. It was observed that when the compaction level was increased, the stability of the mix increased initially, it went up to a maximum value and then decreased with further compaction. When the specimen was given 10 blows on each face, Marshall stability of

6.75 kN was obtained. With an increase in the number of blows, the value increased further and an optimum value of 11.62 kN was obtained for a compaction of 50 blows. A further increase in the compaction level produced a reduced effect on the strength of the mix. This may be due to the disintegration of sand particles due to over compaction.

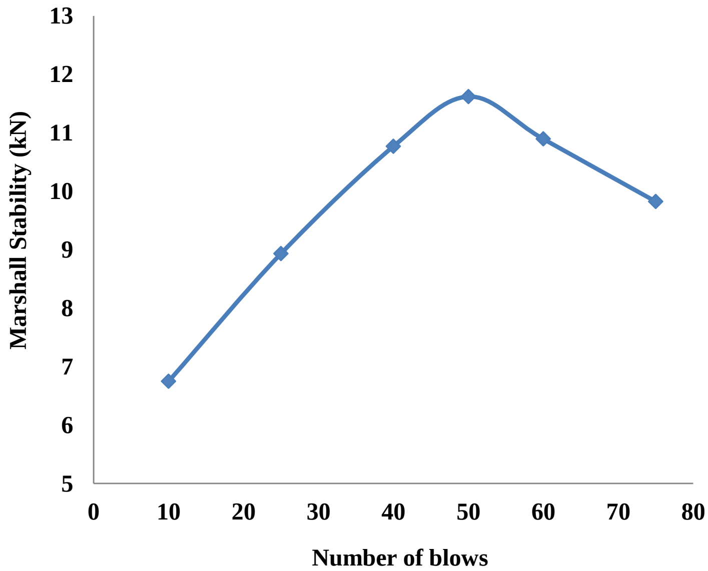

FIGURE 2 Marshall stability of the mix at different compaction level

Unit Weight

Figure 3 presents the effect of level of compaction on the unit weight of the S-S-B mix. An increasing trend was observed in the density of the mix as the compactive effort was increased. The unit weight of the mix increased sharply up to 50 blows, but the increase in the unit weight after 50 blows up to 75 blows is only marginal. At 10 blows of compaction, a unit weight as low as 8.18 kN/m^3 was obtained. A higher compactive effort was noted to have considerable improvement on the density of the mix. For a compaction of 50 and 75 blows, the unit weights of S-S-B mix were 19.68 kN/m^3 and 19.80 kN/m^3 respectively. This may be explained as follows. With increase in the compactive effort, the aggregate fraction, *i.e.*, only sand particles tend to come close to each other thereby increasing the density of the mix. Once they have formed a close knit structure, any further compaction is observed to produce a very slight increase in the density of mix. Hence, it was observed that as far as density of the mix was concerned, 50 blows of compaction were found to be desirable as compaction after that does not bring any significant improvement.

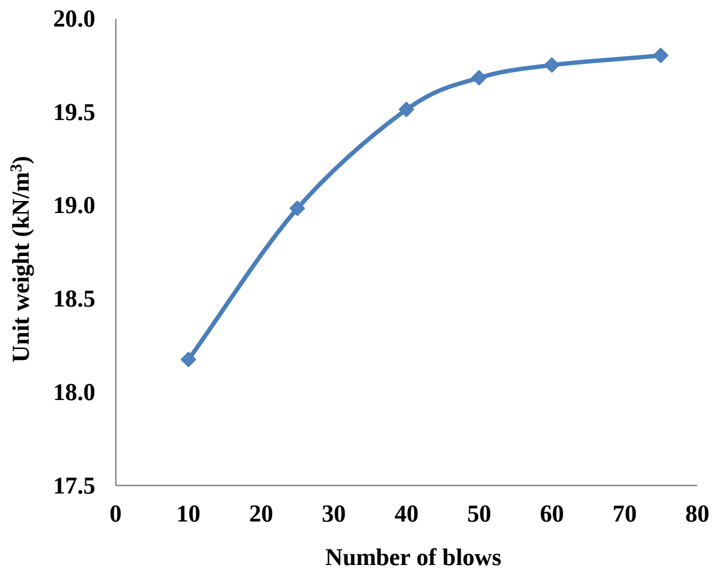

FIGURE 3 Unit weight of the mix at different compaction level

Air voids

The influence of compaction level on the air void content is shown in Figure 4. As the number of blows increased from 10 to 50 blows, the air void content of the mix got reduced from 25.11 % to 18.88 %. At a compaction of 75 blows, the mix was observed to have an air void content of 18.39 %. Hence, it is noticed that the increase beyond 50 blows is very less and can be assumed to be almost constant.

The air void content of the mix obtained was found to be much more than specified by MoRTH (2013) (*10*), due to the use of poorly graded sand as aggregates. The relatively high air void content of S-S-B mixes is undoubtedly not desirable when considering the field applications. However, it has been pointed out by Deme (*3*) that the relatively high air void content of the S-S-B mixes does not imply that they are permeable.

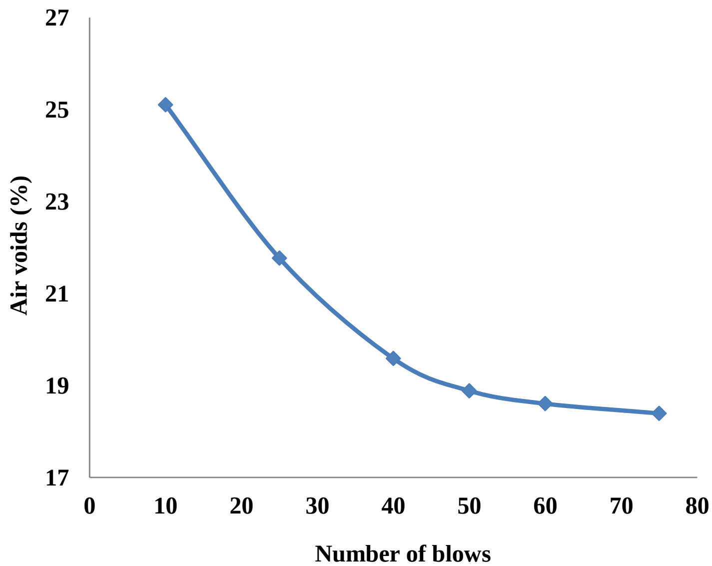

FIGURE 4 Air void content of the mix at different compaction level

Flow value

Figure 5 presents the relationship between flow values of the mix with the compactive effort applied. Flow values decreased initially till 50 blows of compaction and thereafter increased with increasing compactive effort. The flow value of the S-S-B mixes ranged between 2.95 and 2.45 over the entire range of compactive efforts. As the number of blows increased from 10 to 50 blows, the sulfur and asphalt coated sand particles became closer and closer, and thus the mixture had more resistance to the deformation. As a result, initially the flow value of the mix increased with increasing number of blows. But compaction beyond 50 blows resulted in breakdown of the particles and hence it provided a less resistance to deformation; thus an increasing trend in the flow value was noticed.

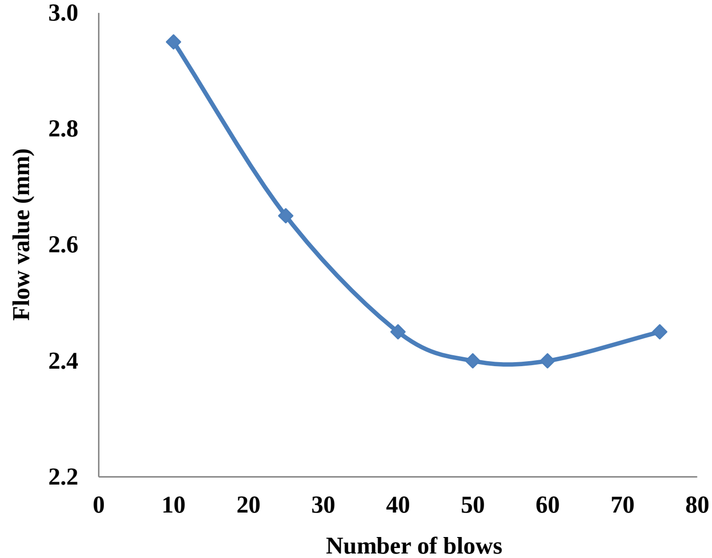

FIGURE 5 Flow values of the mix at different compaction level

SUMMARY

In this study, an investigation was directed towards optimizing the compaction level, *i.e.*, the number of blows (in Marshall compaction) applied to S-S-B mix so as to obtain maximum performance quality of the mix. The Marshall characteristics of the mix were evaluated and the results were analyzed for drawing the following conclusions. The major findings of this investigation are summarized as follows:

- It was observed that the compactive effort has a significant influence on the Marshall characteristics of the S-S-B mix.
- An optimum value of Marshall stability, *i.e.*, 11.62 kN was attained for a compaction of 50 blows given on each face of the sample. Further compaction was noticed to have a decreasing effect on the strength of the mix.
- The compactive effort has a noticeable influence on the improvement of the densification of the mix. The density increases with compaction from 10 blows to 50 blows but the increase in density was noticed to be practically insignificant with further compaction.
- The air voids of the mix, decreases initially up to a compaction of 50 blows and, thereafter remains more or less constant. However, the use of almost single sized fraction of sand

considered as aggregates results in higher air voids than the specified limit prescribed by MoRTH (2013) for bituminous surface courses.

- It is concluded that 50 blows of compaction on each face of the specimen are optimum for S-S-B mix as compaction beyond 50 blows have no significant benefit. For mixes compacted at optimum compaction level, Marshall stability values as high as 11.62 kN and flow value of 2.4 mm are observed which satisfies the MoRTH specification of a minimum stability of 9.0 kN and flow value of 2-4 mm for dense bituminous mixes.
- Hence, this investigation indicates that the air void content being more as compared to the recommended values, the S-S-B mix as discussed, may be considered for lower binder courses in flexible pavements.

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