Effect of Flyash on Engineering Properties of Sand-Asphalt-Sulfur Paving Mixes

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A sand-asphalt-sulfur (SAS) mix has been considered by many as an alternative to asphalt concrete mixes. One of the drawbacks of SAS mixes is their high air void content. The results of a study on the effect of flyash filler on the air voids and other engineering properties of SAS mixes are presented. It was found that compared with SAS mixes, sand-asphalt-flyash-sulfur mixes have, in general, higher stability values and lower air voids. The static tensile and flexural properties have been studied for some mixes. The flexural strength and fatigue life under repeated loading of some selected mixes generally have been found to be higher than those of an asphalt concrete mix.

Sand-asphalt-sulfur (SAS) mixes have been suggested by investigators (*1,2*) as a possible alternative to asphalt concrete mixes, particularly in areas where there exists a shortage of good-quality coarse aggregates. It has been found that SAS mixes in general possess satisfactory stability values. However, one of the drawbacks of SAS mixes is that they have very high air void contents compared with asphalt concrete mixes. Most of the investigators observe that this high air void content in a SAS mix is not harmful because of its low permeability characteristics (*3–5*). However, one of the ways in which the air voids may be decreased is by the addition of a suitable filler. Such an addition may give rise to an increase in strength characteristics too. This paper presents the results of an investigation of the effect of adding flyash dust to a SAS mix, resulting in a sand-asphalt-flyash-sulfur (SAFAS) mix. The disposal of flyash is a major problem in most thermal power plants; hence, the use of flyash in paving mixes may contribute significantly to solving this problem.

MATERIALS

Sand

River sand was obtained from the bed of the river Kansai, which originates in the western hilly tracts of West Bengal and flows into the Bay of Bengal. The gradation of the sand (Figure 1) indicates that it is a poorly graded sand with a uniformity coefficient of 2.4 and specific gravity of 2.69.

Flyash

Flyash was obtained from a nearby thermal power plant (Kolaghat) and has a specific gravity of 2.15. The fraction passing an ASTM 200 sieve was used, the hydrometer analysis of which is presented in Figure 2.

Asphalt

Asphalt was 80–100 penetration-grade bitumen, which is widely used in India. The softening point (R&B), ductility at 27°C, and specific gravity are 41°C, 100^+ cm, and 1.02, respectively.

Sulfur

The sulfur was powdered, commercial-grade sulfur having a specific gravity of 2.03.

TEST PROGRAM

Four types of tests were carried out to evaluate the mixes: Marshall test, indirect tensile test, static flexure test, and repeated load flexure test.

Preparation of Mixes

Different fractions of sand, washed and dried to constant weight, were mixed according to the natural gradation. In the SAFAS mixes, in which a part of the sand was to be replaced by an equal weight of flyash, the required amount of flyash was mixed uniformly with the sand. The sand or sand plus flyash was heated to 150°C and mixed thoroughly with asphalt heated to 140°C. Time of mixing varied from 3 sec to 1 min, depending on the constituents and their proportions. In the meantime, sulfur was heated to 140°C and then mixed thoroughly with the hot sand-asphalt mix in a second mixing cycle. The time required for this cycle was about 30 sec. The mix was then poured into the Marshall or beam molds heated to 140°C and compacted in the manner described later.

Marshall Test

The Marshall test was carried out on the mixes according to ASTM D1559. The specimens were compacted by giving 10 blows on each face of the specimens. As a result of a series of tests on specimens compacted under various compactive

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SIEVE SIZE mm	PERCENT PASSING
2.360	100
1.180	96
0.600	86
0.425	46
0.300	25
0.150	3
0.075	0.5

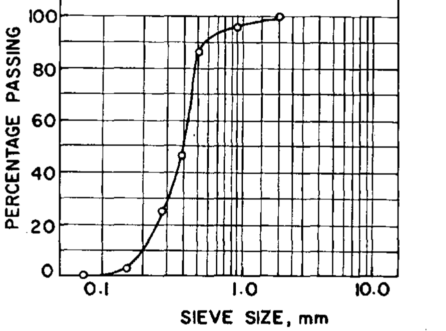

FIGURE 1 Gradation of sand.

efforts, it was decided that 10 blows on each face would be the optimum compactive effort (*6*).

Three series of mixes, each containing a fixed proportion of sand plus flyash—80, 82, and 85 percent—were considered. In each of these series, three flyash contents (5, 7, and 10 percent) and one without flyash were used. Last, in each set of mixes containing a particular sand content and flyash content, asphalt and sulfur contents were varied. In general, the asphalt content was varied from 5 to 8 percent. A total of 60 mixes were tested. In general, four samples per mix were tested. However, more samples were cast in certain cases to get consistent results, resulting in a total specimen number of 245.

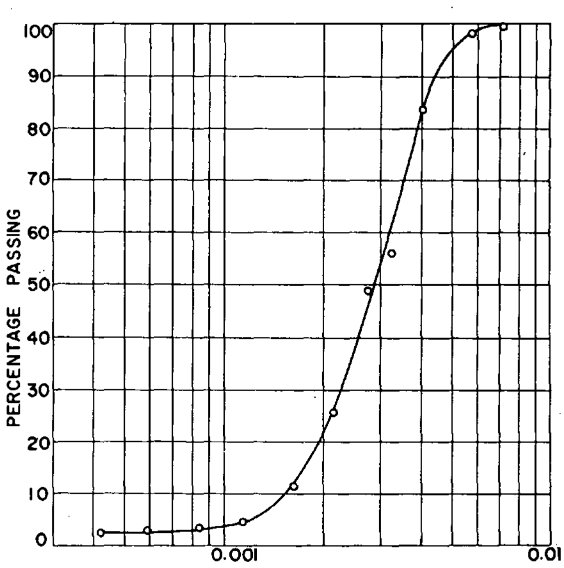

FIGURE 2 Gradation of flyash.

Indirect Tensile Test

The static split cylinder (Brazilian) test was used to determine the tensile strength of a few mixes. Cylindrical specimens of the size of Marshall samples were subjected to a line load (strip width of 1.25 cm) in a compression testing machine at a test temperature of 20°C and rate of displacement of 0.25 mm/min. The tensile strength was calculated on the basis of the equation suggested by Kennedy (*7*).

The test was carried out on 11 mixes, one from each set, selected on the basis of their Marshall stability values. No mix was tested from the set containing 85 percent aggregate and 10 percent flyash content because of their poor Marshall properties. The number of specimens tested was 45.

Flexural Strength Test

The modulus of rupture, which measures the flexural strength of the mixes, was determined by subjecting simple rectangular beams to third-point loading. The beam specimens (254 × 65 × 50 mm in size) were cast in a steel mold and compacted to the respective Marshall density of the mixes. The beams were tested the next day at the same temperature and rate of loading as in the indirect tensile test. Forty-four specimens were tested.

Flexure Test Under Repeated Load

For a proper evaluation of a paving mix, its flexural and fatigue characteristics are of vital importance because these provide more relevant inputs for pavement design.

Four mixes were selected for this test. Beam samples were prepared as in the case of the static flexure test. These beams were subjected to a repeated two-point load in equipment fabricated for this purpose. A haversine form of load was applied through rollers by a double-acting cylinder (Figure 3). The frequency chosen was 75 cycles/min with a loading time of 0.2 sec. The test temperature was 30°C ± 0.5°C. Eight specimens, on an average, for each stress level were tested.

TEST RESULTS AND DISCUSSION

Marshall Stability

Figure 4 indicates the nature of variation of the Marshall stability values with varying flyash contents for different sand plus flyash content mixes. It can be seen that the stability values increase with increasing flyash content. The reason for this may be that flyash, which is finer than sand, goes into the voids of sand and serves to interlock the particles, thereby increasing the stability. However, for 85 percent aggregate content, the stability decreases after 5 percent flyash content. This probably happens because in this case the bitumen content is insufficient to cover completely the very large surface area created by the aggregate in the mix.

The maximum stability values obtained are 31.44 and 36.44 kN for 80 and 82 percent aggregate contents, respectively, with both mixes containing 10 percent flyash. For 85 percent

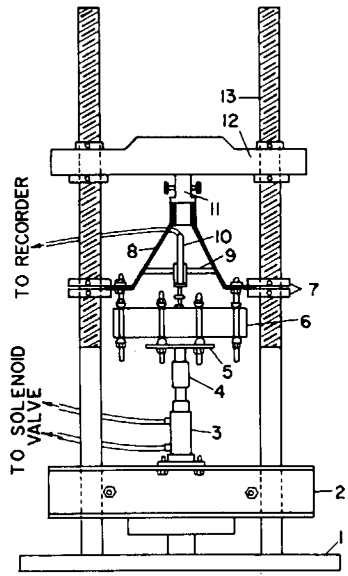

FIGURE 3 Repeated flexure test setup: 1, base of loading frame; 2, supports; 3, double-acting cylinder; 4, adapter; 5, loading plate; 6, test specimen; 7, support holders; 8, suspended frame; 9, frame stiffener cum LVDT holder; 10, LVDT; 11, hanger; 12, movable head; 13, vertical guide rods.

aggregate content, the maximum stability value achieved is 13.19 kN at 5 percent flyash content. Of the 40 SAFAS mixes tested, 32 mixes have stability values greater than 3.4 kN, which is the minimum value specified for asphalt concrete mixes for heavy traffic.

Unit Weight

Figure 5 shows that flyash content has significant effect on the unit weight of the mixes. Up to certain percentages flyash increases the unit weight significantly. The initial increase in unit weight may be attributed to the fact that flyash occupies the voids in the sand particles, thereby increasing the density. The reason for the subsequent decreasing trend is that, after a certain flyash content, the relatively larger amount of flyash pushes out the sand particles while creating more voids within itself.

Air Voids

Figure 6 indicates that the variation of air voids with flyash content is almost the inverse of that of unit weight. In the 80 percent aggregate content series, the air void content in SAS mixes ranges between 16.57 and 21.02 percent. In the SAFAS mixes, the air void content has been reduced to values ranging from 9.81 to 14.24 percent. In the 82 percent aggregate content mixes, the void contents of SAS mixes vary between 17.46 and 25.08 percent, whereas the void contents for similar SAFAS mixes are reduced to between 5.44 and 14.85 percent, indicating that the reduction is all the more significant in this case compared with the 80 percent series. The effect in the 85 percent series is not as great as in the other two series. Here the SAS mixes have void contents ranging from 22.16 to 25.17 percent, whereas for the SAFAS mixes the air void content varies from 16.32 to 23.37 percent.

Flow

Figure 7 shows that the flow decreases with increasing flyash content in the 80 and 82 percent aggregate series, whereas the flow increases after the initial decrease in the 85 percent

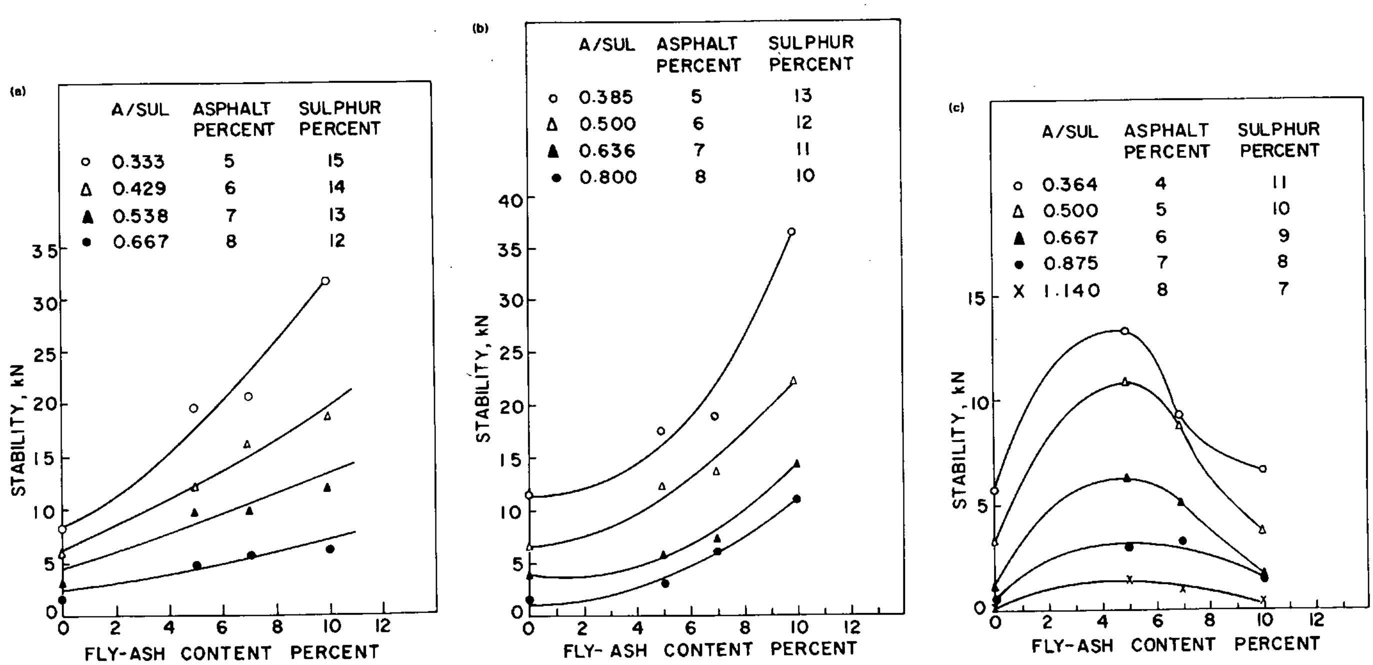

FIGURE 4 Variation of Marshall stability with flyash content for (*a*) 80, (*b*) 82, and (*c*) 85 percent sand plus flyash series.

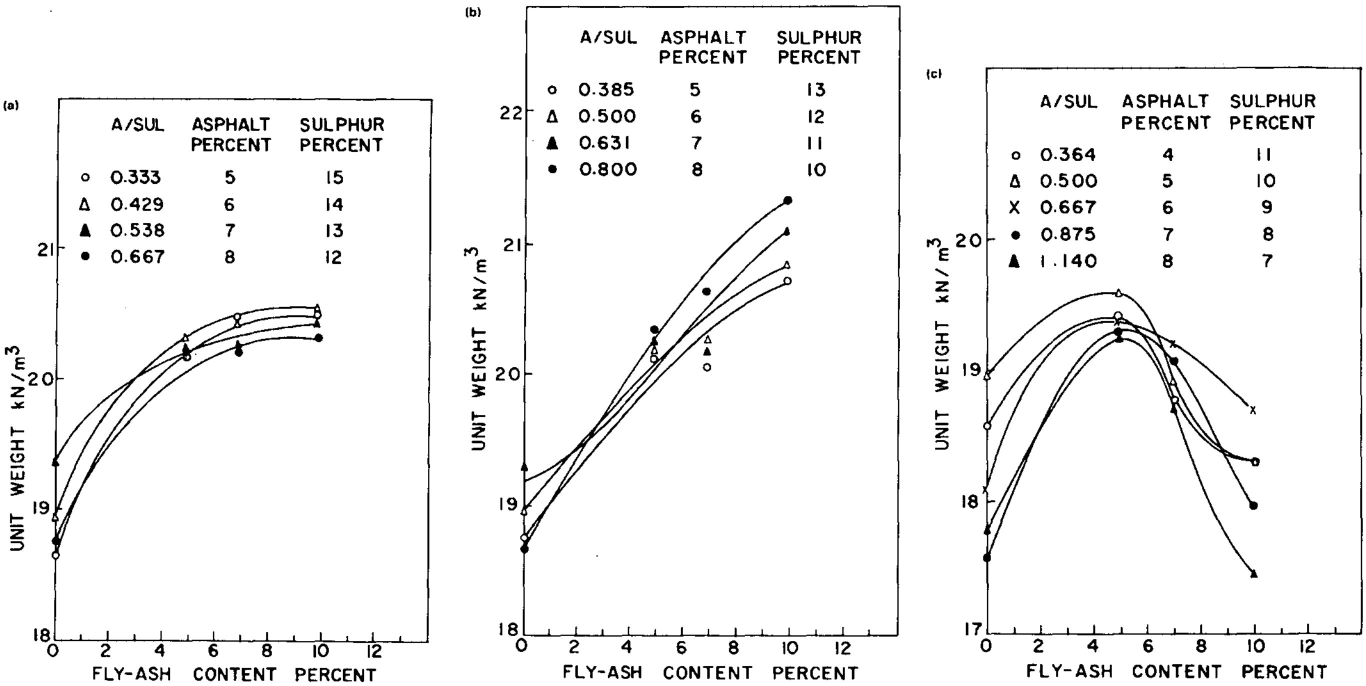

FIGURE 5 Variation of unit weight with flyash content for (*a*) 80, (*b*) 82, and (*c*) 85 percent sand plus flyash series.

series. The reduction of flow values may be attributed to the increased interlocking offered by flyash particles and to the relatively low quantity of asphalt. For the 85 percent aggregate content, the subsequent increase in flow values may be because of the large surface area, resulting in incomplete coating.

Tensile Strength

Tensile strength data for SAFAS mixes are given in Figure 8. The results indicate significant improvement in tensile strength for flyash content that is between 7 and 10 percent, whereas the improvement is nominal for flyash content lower than 7 percent. In the case of 85 percent aggregate content mixes, the tensile strength decreases.

Flexural Strength

Figure 9 indicates the flexural strength data for SAFAS mixes. In this case, too, flyash content significantly affects the strength value, except for the 85 percent aggregate content mixes.

Flexural Properties Under Repeated Loading

Figure 10 shows a typical relationship obtained between the dynamic flexural modulus and the flexural stress, whereas

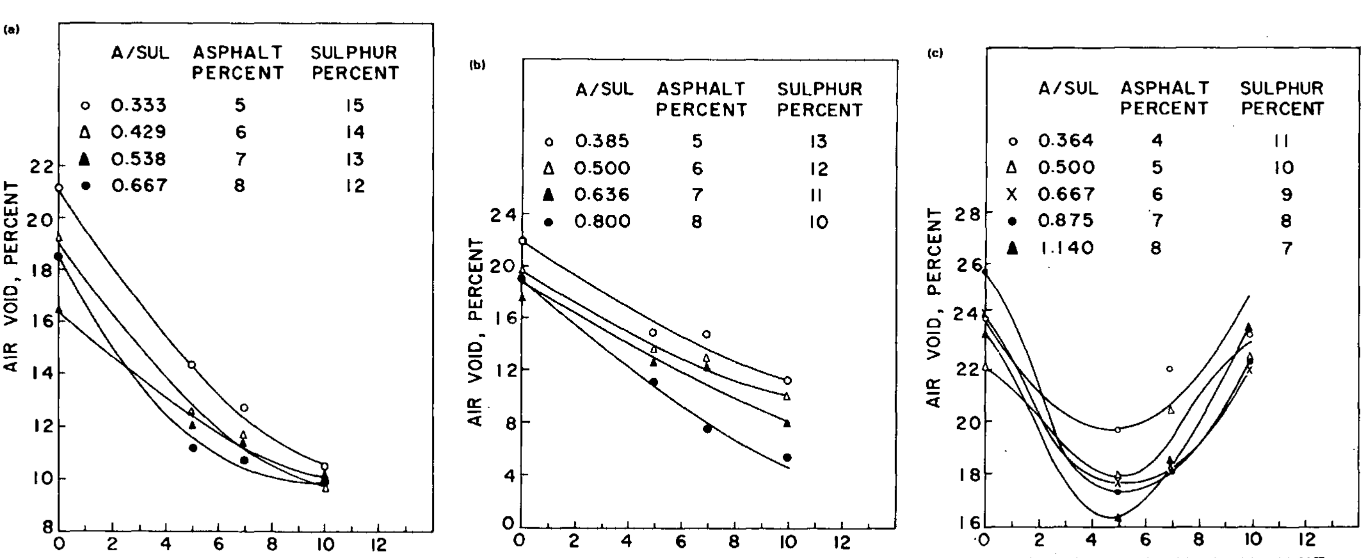

FIGURE 6 Variation of air voids with flyash content for (*a*) 80, (*b*) 82, and (*c*) 85 percent sand plus flyash series.

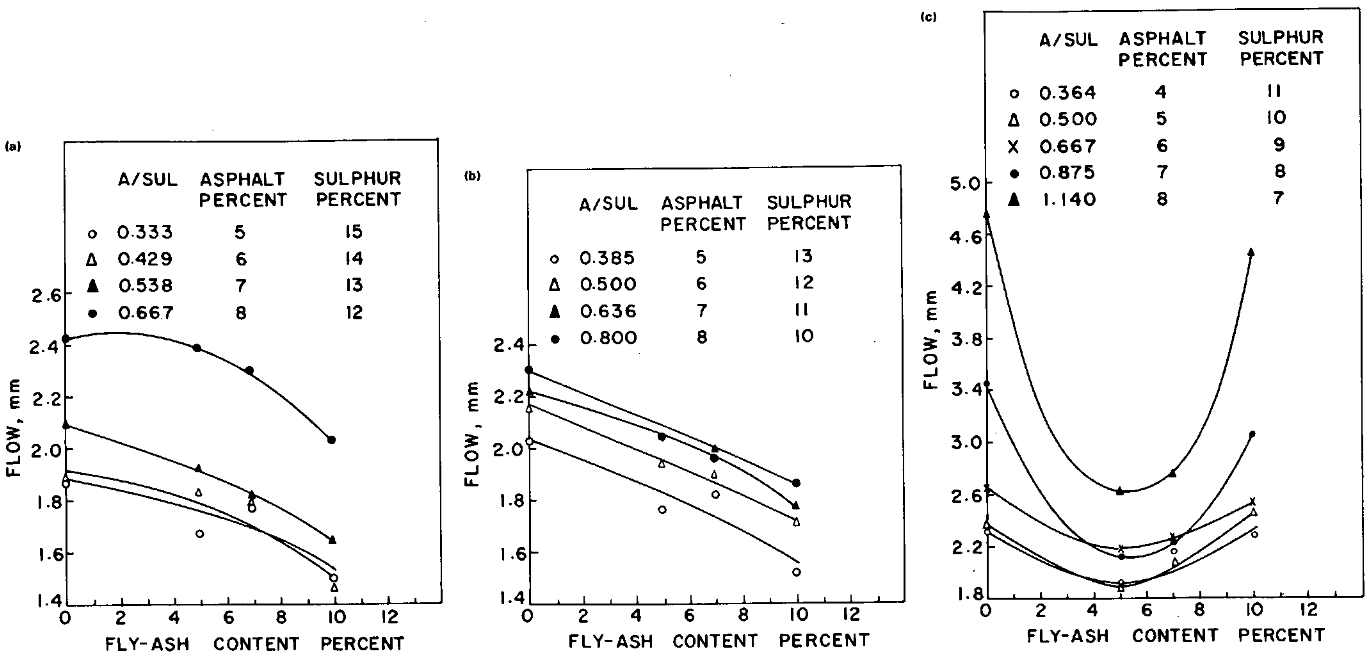

FIGURE 7 Variation of Marshall flow with flyash content for (*a*) 80, (*b*) 82, and (*c*) 85 percent sand plus flyash series.

Figure 11 shows the fatigue behavior of the same mix. The average value of the elastic modulus is about 1,400 MPa, which is quite high compared with the 700 MPa value obtained in a separate study (*8*) for a dense-graded asphalt concrete mix at the same temperature.

Stresses developed in and the fatigue life of pavements consisting of the same assumed thickness of 30 cm of one SAFAS mix and an asphalt concrete mix have been calculated using the relationship given by Lister and Jones (*9*). The SAFAS mix has the composition of 72-5-10-13, whereas the properties of the asphalt concrete mix have been taken from another study (*8*). It has been found that under the same conditions of loading time (0.02 sec), subgrade CBR (3 percent) and temperature (30°C), the fatigue lives of the SAFAS and the asphalt concrete mixes are 5.84×10^6 and 1.05×10^5 load repetitions, respectively.

CONCLUSIONS

A SAS mix has low strength properties and high voids content. Introduction of 5 to 7 percent flyash (fraction passing ASTM 200 sieve) gives the following beneficial results:

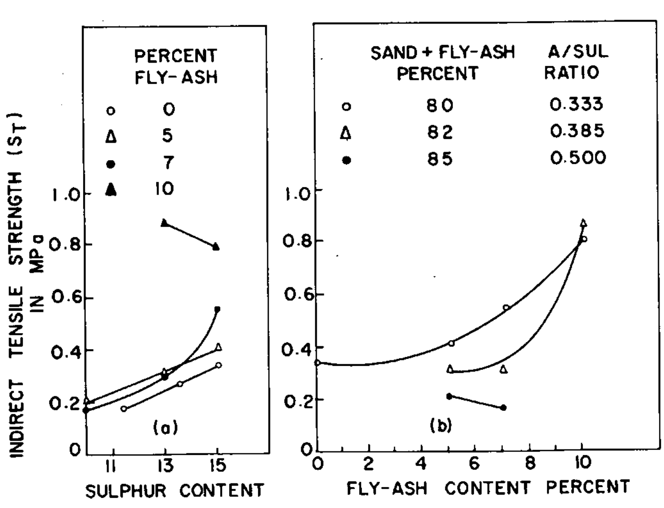

FIGURE 8 Relationship between indirect tensile strength and (*a*) sulfur content and (*b*) flyash content.

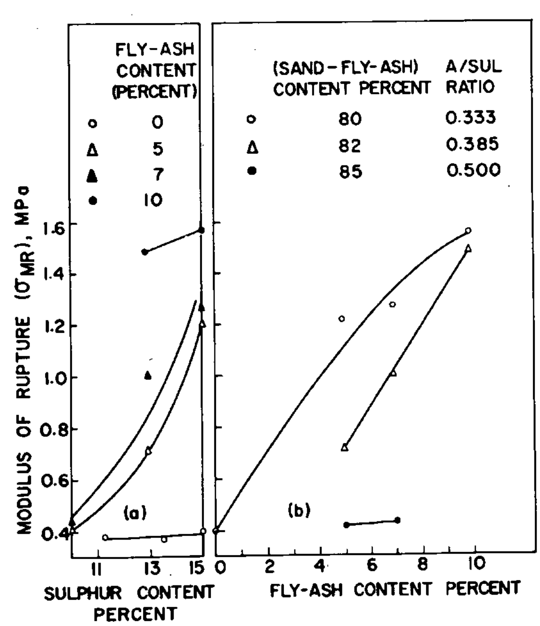

FIGURE 9 Relationship between modulus of rupture and (*a*) sulfur content and (*b*) flyash content.

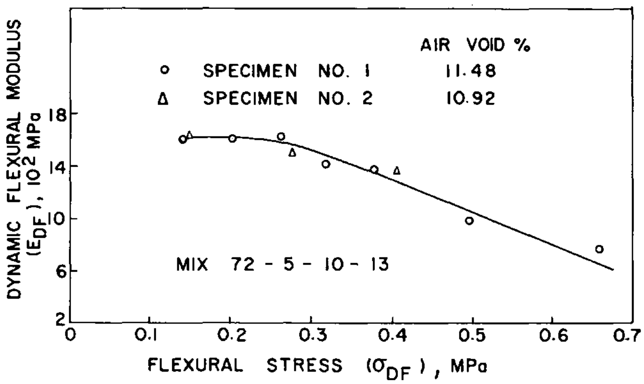

FIGURE 10 Relationship between dynamic modulus and flexural stress.

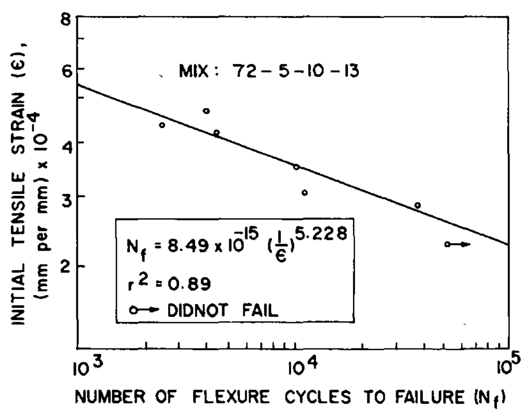

FIGURE 11 Relationship between repeated flexural stress and fatigue life.

1. Considerable increase in the Marshall stability value;
2. Significant improvement in the void properties;
3. Increase in the tensile and flexural strength; and
4. Improvement in the flexural fatigue life, which in some cases is greater than that of dense-graded asphalt concrete mixes.

The use of SAFAS mixes in pavements would go a long way in solving the problem of a shortage of aggregate in certain areas. Apart from removing the necessity of hauling aggregates from a considerable distance, the use of SAFAS may reduce the ecological damage caused by excavating borrow areas and hillsides. An additional benefit is the use of flyash, the disposal of which is a great problem.

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