# Evaluation of Dune Sand and Asphalt Mixes Containing Different Amounts of Crusher Waste Dust

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An attempt was made to characterize the dune sand and asphalt mixes containing crusher waste dust. Dune sand and asphalt mixes were found to be weak, easily deformable, and to contain a considerable amount of air voids. The optimum asphalt content from results of Marshall stability and split tensile strength tests was about 12 percent by weight of sand. The properties of such mixes were improved to a great extent by introducing crusher waste dust into the blend. Five percentages of dust by weight of dune sand were used; namely, 10, 20, 30, 40, and 50 percent. Not only the content of air voids and the optimum asphalt content were reduced by the dust, but also the stability, split tensile strength, and resilient modulus were significantly increased. The modified sand mixes that were developed have a great potential for being used in low- or medium-volume roads, particularly in areas where good-quality aggregate is scarce and dune sands are abundant.

In the last decade and a half, the Kingdom of Saudi Arabia has passed through a period of extremely rapid rate of infrastructural developments. Construction of hundreds of kilometers of freeways, urban arterials, and agricultural roads is an important sector of such development. Growth in socioeconomic and industrial sectors has also generated a great deal of intra- and intercity vehicle transportation.

The Kingdom of Saudi Arabia has nearly completed the construction of principal highways and expressways that link main cities. The development of paved highways (primary, secondary, and feeder) over the period 1970 to 1987 is shown in Figure 1 (*1*). The length of paved highways has tremendously increased over this period. The increase in the length of agricultural roads for the same period is shown in Figure 2 (*1*). The majority of existing low-volume roads are dirt tracks (unpaved) that are hazardous and require continuous maintenance. One suggestion for improving and upgrading the quality of these roads was to cover them with asphalt concrete layers. The high percentages of these low-volume roads that run through sand dune areas, coupled with the high cost of scarce good-quality aggregate that is imported from other localities, necessitate the upgrading of the locally available dune sands for such construction purposes.

The primary objective of this research was to evolve suitable techniques for using locally available marginal aggregates for construction of low-volume roads.

Sand and asphalt mixes made with wind-blown sands are characterized by high content of voids and low strength. One approach for improving the strength of such mixes is to alter the gradation and hence modify the voids ratio by introducing crusher waste dust into the dune sand and asphalt mixes.

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## MATERIALS USED

### Dune Sand

Dune sand is available in abundant quantities in Saudi Arabia. The dune sand selected was obtained from the Al-Thumamah area northeast of Riyadh. The sand consists of rounded, subrounded, and subangular grains with a hard, smooth surface texture. The sand is essentially a single-sized material with a nominal maximum size of Sieve #30 and almost no materials finer than Sieve #200. The sand has a uniformity coefficient of about 2. The grain size distribution for this sand is shown in Figure 3. The physical properties of the dune sand used are presented in Table 1.

### Crusher Waste Dust

The crusher waste dust materials were collected from a crusher site in Al-Dariyah, north of Riyadh. This material is a byproduct of aggregate scalping and crushing of limestone boulders, which are weak. This material is produced in vast quantities, creating a disposal problem. The gradation of the crusher waste dust and results of the tests conducted on such materials are presented in Tables 2 and 3.

### Asphalt

Asphalt cement of grade 60/70 penetration, which is widely used for hot mixes in Saudi Arabia, was used throughout this study. Results of various tests performed on the asphalt are presented in Table 4. When the test results were compared to ASTM specifications, the results indicated that the asphalt used was within the specified limits.

## SAMPLE PREPARATION

Six different percentages of crusher waste dusts were blended with dune sand: 0, 10, 20, 30, 40, and 50 percent of crusher waste dusts by weight of sand. These blends are hereafter designated as blends SF–0, SF–10, SF–20, SF–30, SF–40, and SF–50, respectively.

The precalculated weight of combined aggregate was adjusted to produce a compacted Marshall specimen that was heated in an oven at 180°C ± 2°C for at least 4 hr. The asphalt was heated in small containers to 155°C ± 3°C in an electric oven for not more than 1 hr. These two temperature values were used to ensure that the mixing and compaction temperatures were 155°C ± 4°C and 144°C ± 4°C, respectively. The mixing and compaction temperatures were established from the viscosity versus temperature chart for the asphalt cements used, which corresponded to viscosities of 170 ± 20 and 280 ± 30 centistokes, respectively (*2*). The hot-aggregate mix (sand and desired portion of crusher waste dust) was dumped into a preheated mixing bowl and mixed thoroughly by hand. The required amount of heated asphalt was then added to the aggregate mix. Mixing was performed with a mechanical kitchen mixer type Hobart N–50 mixer at medium speed for about 1.5 min to ensure a uniform dispersion of asphalt. The hot mixture was then compacted in Marshall molds using a Marshall electric compactor consisting of a 10-lb hammer falling through a height of 18 in. Fifty blows on each side were applied. This number of blows was appropriate for the traffic category (i.e., for roads of low traffic volume).

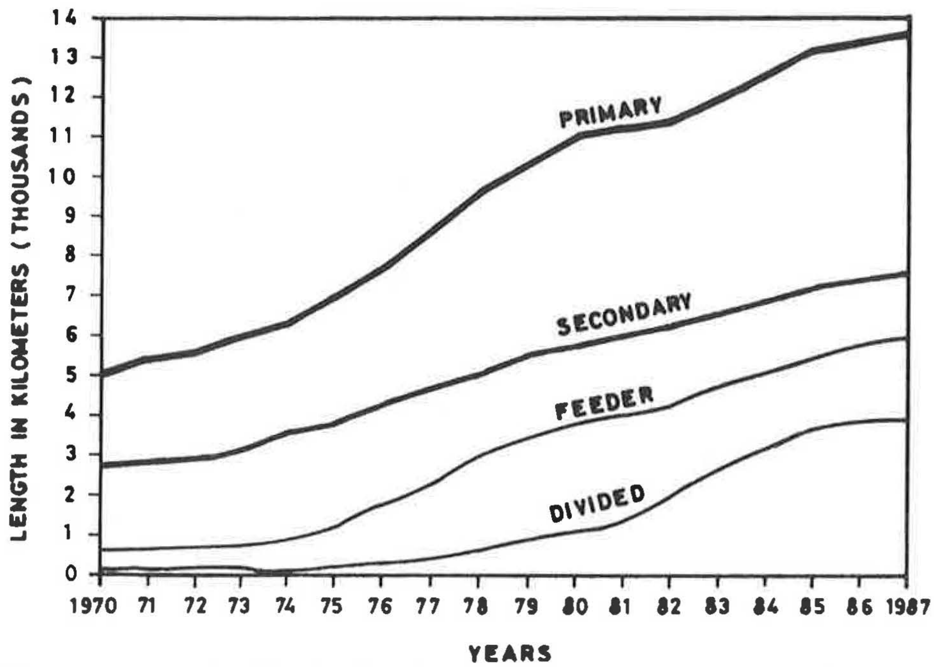


FIGURE 1 Accumulated lengths of paved roads.

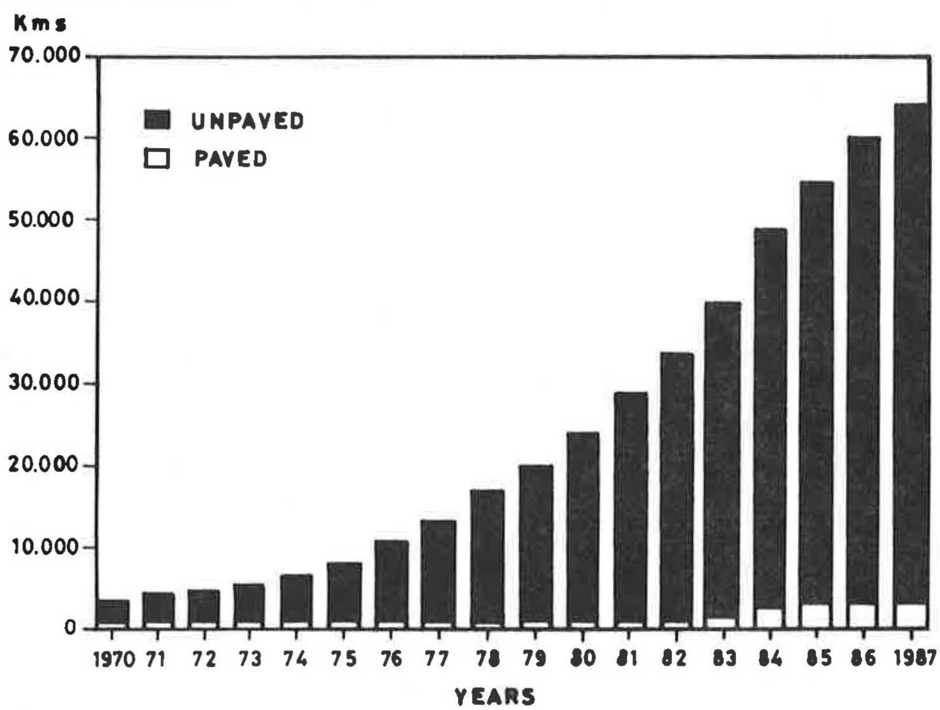


FIGURE 2 Accumulated lengths of agricultural roads.

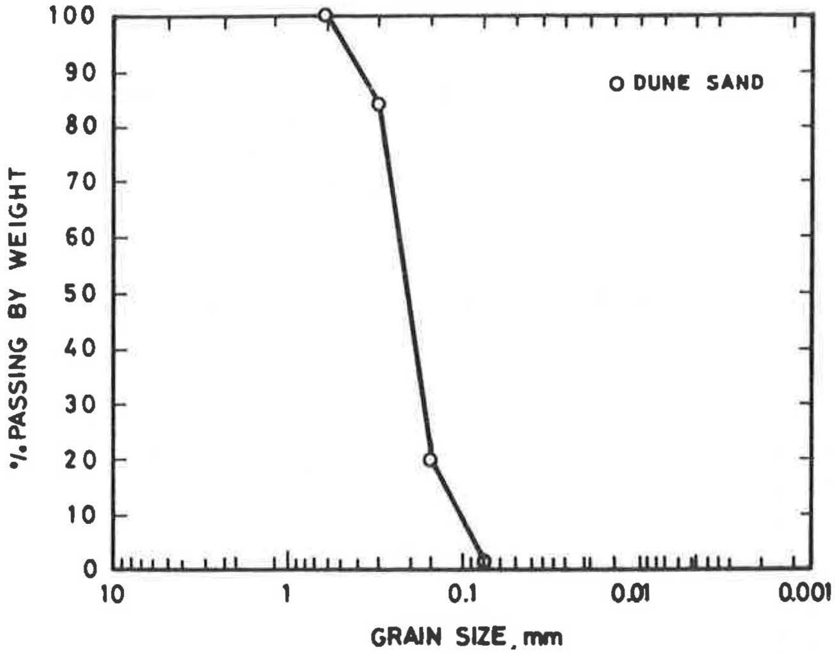


**FIGURE 3 Gradation of dune sand (ASTM C-136).**

TABLE 1 PHYSICAL PROPERTIES OF DUNE SAND USED

| Property | ASTM Designation | Value |
|---|---|---|
| Bulk specific gravity: | | |
| - Oven dry condition | C-128 | 2.653 |
| - Saturated surface dry condition | C-128 | 2.663 |
| Apparent specific gravity | C-128 | 2.680 |
| Water absorption (%) | C-128 | 0.370 |
| Sand Equivalent value (%) | D-2419 | 77 |
| Centrifugal kerosene equivalent (CKE) | | 4.5 |

## LABORATORY TESTS

The prepared specimens of the entire mixes were evaluated using Marshall stability, unit weight and voids analysis, static testing to determine the indirect tensile strength, and dynamic testing to determine resilient modulus. Tests for all mixes were run on Marshall-sized specimens, 4 in. in diameter and 2.5 in. in height, fabricated at different ratios of asphalt contents and filler to sand. Two duplicates of each sample were used throughout this study.

Samples to be tested for indirect tensile strength were prepared and maintained at 25°C for at least 2 hr to ensure constant temperature through the sample. The samples were then tested at a stroke rate of 2 in./min until failure. The ultimate load was recorded to determine the indirect tensile strength from the following equation (*3–5*):

$$\sigma_t = 2P/\pi dt \quad (1)$$

where

$\sigma_t$ = split tensile strength (psi),
$P$ = total applied load at failure (lb),
$t$ = specimen thickness (in.), and
$d$ = specimen diameter (in.).

For each mix, the average $\sigma_t$ value for each set of two samples was calculated.

The diametral resilient modulus is obtained from a dynamic test response by which the elastic modulus of asphalt mixes can be determined. The test consists of applying a repetitive dynamic load diametrally on the specimen and measuring the corresponding horizontal resilient strain by use of linear variable differential transformers (LVDTs) at various numbers of load repetitions. The system used to test the specimens was that for the repeated diametral test described in ASTM D4123. Loads and strains were recorded with a two-channel oscillographic recorder. The specimens were tested using a pulse load duration of 0.1 sec applied at a frequency of 0.5 Hz. A seating load of 10 lb was used to prevent hammering action and to hold the specimen in place. Four levels of pulse loads, 50, 100, 150, and 200 lb, were selected. These loads were selected to ensure that the applied load could engage 10 to 50 percent of the tensile strength of the specimen, as recommended by ASTM D4123. Room temperature was maintained at 25°C throughout the test period by conducting the test inside a controlled-temperature chamber.

The resilient modulus $M_r$ was calculated using the following equation (*6*):

$$M_r = \frac{P_r(\mu + 0.2734)}{t \cdot \Delta H} \tag{2}$$

where

$P_r$ = applied dynamic pulse load (lb),
$\mu$ = Poisson ratio (= 0.35 for asphaltic materials),
$t$ = specimen thickness (in.), and
$\Delta H$ = total horizontal elastic strain (in.).

Before taking any reading, 50 or more load applications were applied to properly seat the loading strips on the specimen (*7*), and to allow the deformation to stabilize.

## TEST RESULTS AND DISCUSSION

A presentation of the entire results for the mixes investigated would be lengthy. The shapes of the curves found for the different types of mixes were identical and in general agreement with the normal shape of the curves for Marshall stability, density, voids ratio, voids in mineral aggregate (VMA), tensile strength, and resilient modulus. Typical mix design results for mix SF–30 are shown in Figures 4–6. A summary of the properties of the sand and asphalt mixes at optimum bitumen content, as a function of filler content, is indicated in Table 5 and Figure 7. The optimum asphalt content values were obtained from results of the Marshall stability, split tensile, and resilient modulus tests.

TABLE 2 HYDROMETER ANALYSIS FOR CRUSHER WASTE DUST

| Particle diameter (D), mm | % Finer |
|---|---|
| 0.075 | 100.00 |
| 0.0488 | 96.7 |
| 0.0356 | 90.8 |
| 0.0260 | 84.9 |
| 0.0189 | 78.9 |
| 0.0137 | 73.1 |
| 0.0100 | 67.1 |
| 0.0072 | 59.8 |
| 0.0048 | 49.7 |
| 0.0035 | 38.5 |
| 0.0013 | 21.1 |

TABLE 3 CHARACTERISTICS OF CRUSHER WASTE DUST

| Property | Result |
|---|---|
| Apparent Specific Gravity | 2.715 |
| Atterberg Limits: | |
| Liquid Limit (%) | 22.80 |
| Plastic Limit (%) | 17.20 |
| Shrinkage Limit (%) | 15.82 |
| Plasticity Index | 5.60 |

The following trends summarize the basic properties of the mixtures:

1. Marshall Stability. The results generally indicated that stability tends to increase when the crusher waste dust content is increased. The stability values of dune sand and asphalt mixes did not exceed 73 lb at an asphalt content of 12 percent. This low stability at such high and uneconomic asphalt content has been increased by more than 4- and 40-fold by the addition of 10 and 50 percent by sand weight, respectively, of crusher waste dust at even lower optimum asphalt contents. However, the optimum asphalt content monotonically increases with increasing percentage of dust in the range investigated. This increase is explained by the increase in surface area contributed by dust particles with the increase of dust percentage.

The addition of 10 percent crusher waste dust does not improve the stability value to a satisfactory level to sustain traffic loading [specified by the Asphalt Institute to be a minimum of 500 lb for conventional mixes (*2*)] even under low-traffic conditions. This mix is still weak and does not satisfy the minimum criteria of stability. Hence, no further tests were conducted on this mix.

High stability values were possible by increasing the dust content beyond 10 percent. As indicated in Table 5 and Figure 7, stability values greater than 800 lb were obtained by the addition of 20, 30, 40, and 50 percent by sand weight of crusher waste dust. The stability is linearly proportional to the dust content as shown in Figure 7.

The addition of crusher waste dust does not affect the flow values appreciably in the range of asphalt contents investigated. This fact indicates that the stiffness of mixes is not affected by introducing dust.

2. Density. The density of a compacted mix depends on the density of its constituent materials and the percentage of air voids. Because the percentage of air voids is reduced with increasing dust percentage, the density of mixes increases, as

TABLE 4 CHARACTERISTICS OF ASPHALT CEMENT USED

| Property | ASTM Designation | Result | MOC* Specification Min. | MOC* Specification Max. |
|---|---|---|---|---|
| Original Asphalt | | | | |
| Penetration (0.1 mm) @ 25°C (100 g, 5 second) | D5 | 60 | 60 | 70 |
| Kinematic viscosity, cst (135°C) | D2170 | 403 | 200 | - |
| Absolute viscosity by vacuum capillary viscometer, poises (60°C) | D2171-85 | 2459 | - | - |
| Ductility, cm (25°C, 5 cm/min) | D113 | 100+ | 100 | - |
| Flash point (°C) | D92 | 340 | 232.2 | - |
| Fire point (°C) | D92 | 370 | - | - |
| Specific gravity | D70 | 1.035 | - | - |
| Softening point (°C) | D36-86 | 50.2 | - | - |
| Loss on heating (%) | D6 | 0.016 | - | 0.8 |
| Residue from TFOT | | | | |
| Penetration (0.1 mm) @ 25°C (100 gm, 5 sec) | D5 | 41 | - | - |
| Retained penetration, % of original | - | 68.3 | 52 | - |
| Kinematic viscosity, cst (135°C) | D2170 | 553 | - | - |
| Ductility, cm (25°C, 5 cm/min) | D113 | 65 | 50 | - |

*MOC = Ministry of Communications, Kingdom of Saudi Arabia

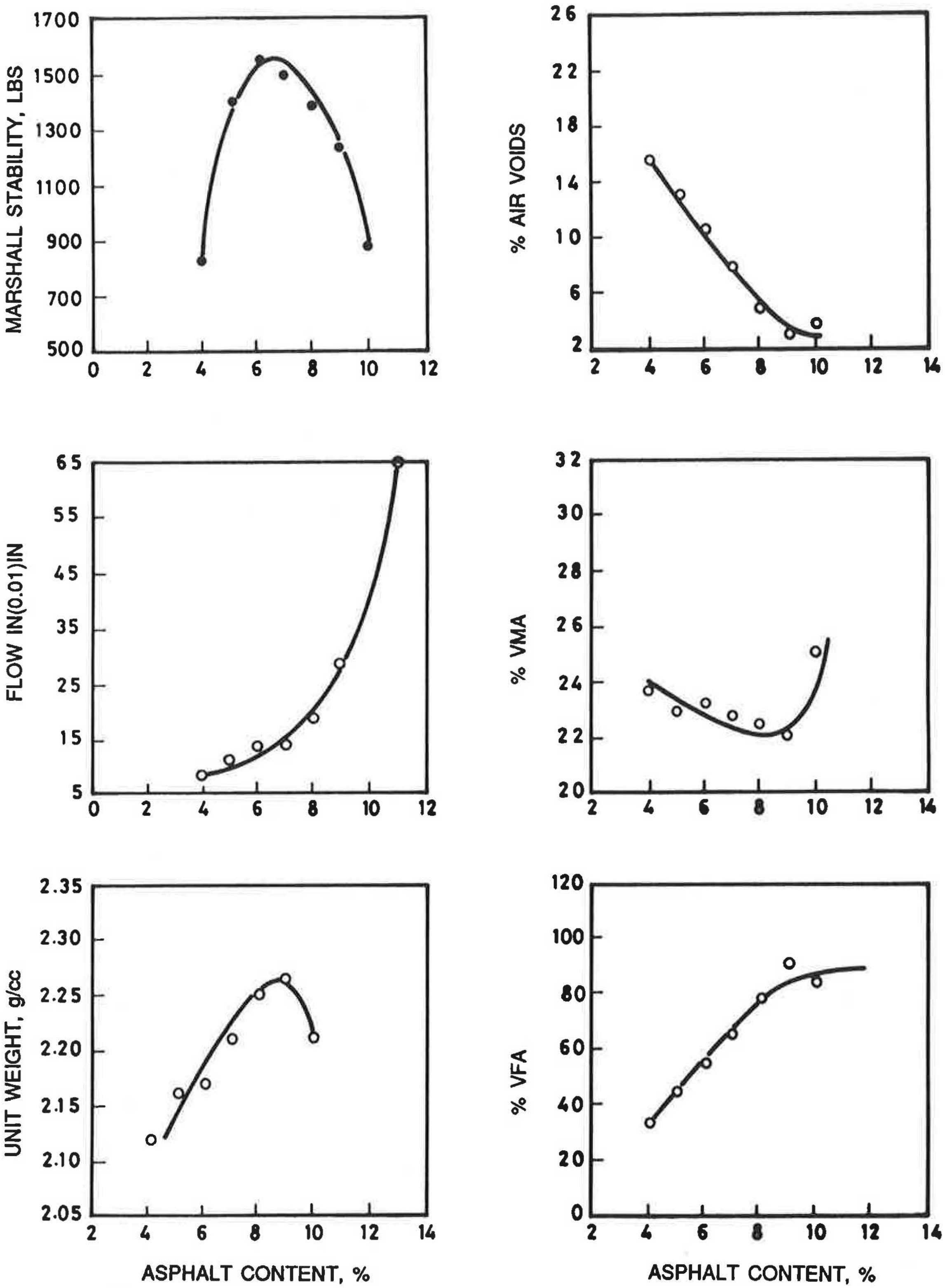


**FIGURE 4** Results of Marshall mix design for SF-30 mixes.

shown in Figure 7. The addition of 50 percent dust causes about a 15 percent increase in the density. The curve tends to peak at 50 percent dust content because there is no more air to be replaced by dust. This behavior is clear from the curve of percentage air voids versus dust content where the curve starts to level off beyond 40 percent dust content.

3. Air Voids and VMA. Air voids content in dune sand and asphalt mixes is extremely high, ranging from 23.5 percent at 5 percent asphalt content to 9 percent at 15 percent asphalt content because the mixes are single-size aggregates having uniform textures. The low percentage of air voids content at optimum asphalt content indicated in Table 5 is attributed to the high optimum asphalt content value of 12 percent. The dust decreases the percentage of air voids by filling the void spaces between the sand particles, hence producing denser mixes.

The addition of 40 percent dust or more produces mixes with percentage of air voids that is below the specified percentage. Therefore, using such high dust percentages should be avoided.

VMA also decreases with increasing dust percentages. The VMA curve shows the same trend as the air voids curve in the sense that it starts to level off when air voids replacement becomes impossible.

4. Split Tensile Strength. From Figure 7, the tensile strength increases as the dust content increases. The dune sand and asphalt mix without any improvement of crusher waste dust had low strength. The strength was improved many times by adding dust.

Mixes with 30 percent or more crusher waste dust had strength values comparable with the strength of conventional mixes. Figure 7 also shows that there might be an optimum dust content for tensile strength because the curve tends to level off, suggesting that the dust in excess of the optimum reduces the free binding agent. Huschek and Angst (*8*) found that the maximum split tensile strength for a pavement mix showed a tendency to peak at an effective filler concentration of approximately 0.6.

5. Resilient Modulus. Results of resilient modulus values for the designated mixes SF-20, SF-30, SF-40, and SF-50 are shown in Figure 7 at their optimum asphalt content values. As the dust content increases, the resilient modulus increases because the increase in stiffness of asphalt mixes is directly proportional to the stiffness of the binder (*9*).

TABLE 5 PROPERTIES OF SAND AND ASPHALT MIXTURES AT OPTIMUM ASPHALT CONTENT FOR VARIOUS AMOUNTS OF FILLER

| Filler Content | Optimum AC, % | Stability (lbs) | Density (g/cc) | % Air Voids | % VMA | ITS (psi) | MR x10$^3$ psi |
|---|---|---|---|---|---|---|---|
| 0 | 12 | 73 | 2.009 | 10.10 | 33.40 | 41.40 | - |
| 10 | 4 | 358 | 1.962 | 21.58 | 29.16 | - | - |
| 20 | 6 | 805 | 2.127 | 12.58 | 24.92 | 86.20 | 125.70 |
| 30 | 7 | 1037 | 2.217 | 7.70 | 22.70 | 115.74 | 170.00 |
| 40 | 7.5 | 2350 | 2.270 | 3.30 | 21.00 | 107.00 | 215.00 |
| 50 | 8 | 2960 | 2.320 | 2.10 | 20.10 | 122.00 | 220.00 |

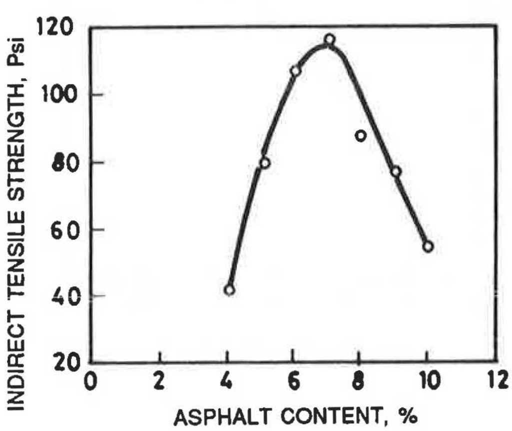


**FIGURE 5 Split tensile strength versus asphalt content for SF-30 mixes.**

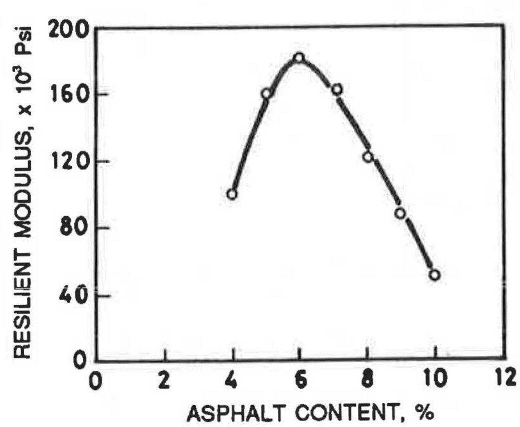


**FIGURE 6 Resilient modulus versus asphalt content for SF-30 mixes.**

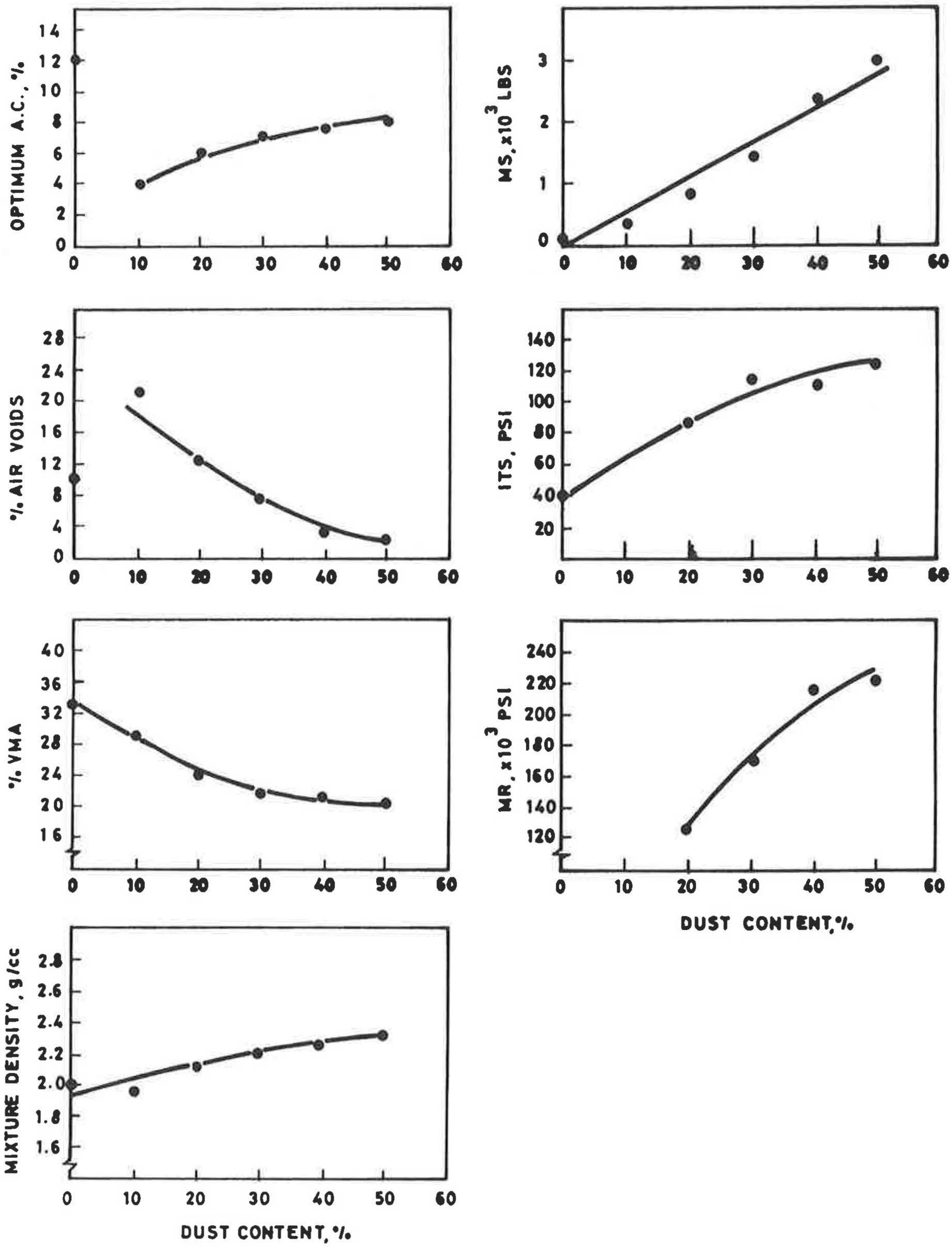


**FIGURE 7** Basic properties of sand and asphalt mixes at their optimum asphalt content, as a function of dust content, and percent by weight of sand.

## CONCLUSIONS

1. Dune sand and asphalt mixes are weak, unstable, and easily deformed under light loads. The mixes are characterized by a considerable amount of air voids content.

2. The dune sand used in this study had an optimum asphalt content of 12 percent by weight of sand. This value was obtained from results of Marshall stability and split tensile strength.

3. The introduction of crusher waste dust to the dune sand and asphalt mixes at different ratios improved the mix properties. The modified sand mixes that were developed have a great potential for use in low- or medium-volume roads, especially in desert-like areas where the dune sands are available in abundant quantities and hot-asphalt concrete mixes are uneconomical.

4. The air voids content of the dune sand and asphalt mixes was reduced by introducing crusher waste dust. The percentage decrease in air voids is directly proportional to the amount of dust added.

5. The optimum asphalt content of sand and asphalt mix was substantially decreased by the introduction of crusher waste dust.

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