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Improvement of Dune Sand Asphalt Mixes for Pavement Bases

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ABSTRACT. Depletion of mineral aggregates is a matter of great concern in most areas of the world. New sources of aggregates need to be investigated. In desert areas, suitable materials for construction of roads are scarce and necessitate either improving available dune sand or importing good quality mineral aggregates. Many industrial by-products are considered wastes costing handling and disposing expenses, in addition to the environmental hazards. This research work looks for beneficial utilization of such wastes for improving dune sand to be used in asphaltic base course. Iron oxide, and kiln dust are considered within this category. A natural material, volcanic tuff dust was mixed with dune sand asphalt and marked improvement was gained.

Portland cement and gypsum were introduced into various percentages with other additives to reach the minimum Asphalt Institute design requirements. The results are very much encouraging with volcanic tuff dust which shows remarkable improvement. However, kiln dust also satisfied the minimum stability requirements for low volume roads.

Introduction

Highway engineers face many problems in designing roads through desert areas. The most eminent of these problems is the unavailability of suitable natural road construction materials. This would necessitate either upgrading the available dune sand material or importing other suitable material to the site, which increases the cost of construction and further depletes high quality mineral aggregates.

Dune sand asphalt mixes are known to be weak and unable to sustain traffic loads without deformation and failure in stability. This type of mix is usually restrained to very light traffic[1] and low temperature environments[2].

To improve the quality of dune-sand asphalt mixes for use as asphaltic concrete pavement for low to medium traffic volume roads, the addition of a third material is required to impart more stability and fatigue resistance to the weak mix. Upgrading can be obtained by introducing finer or coarser materials to the open graded dune sand to alter the gradation so more frictional contact and interlocking between particles will exist[3,4]. The addition of inert cementing material such as sulfur, lime or portland cement to dune sand asphalt mix has proved to increase the stability of the mix by cementing sand particles together[3,5,6].

Other additives could possess good potential to improve the dune sand asphalt mix quality. Iron oxide, and kiln dust are considered to be waste materials which may add considerably to the stability of the mix. A new material such as volcanic tuff might be of a potential in such study.

The main objective of this research is to study the feasibility of developing and using improved dune sand-asphalt cement mix as pavement construction material in areas of the world where dune sands are prevalent.

The study is designed to investigate, based on acceptable laboratory procedures, the utilization and improvement of dune sand asphalt mixes as road bases. To improve the stability of the weak mix, a number of additives were tried to accomplish this aim. The Marshall test method criteria suggested by the Asphalt Institute[1] (ASTM D 1559) were used to determine the acceptability of a mix.

Material

The material investigated in this research consisted of dune sand, asphalt cement, iron oxide, ordinary Portland cement, gypsum, cement kiln dust, and volcanic tuff dust. The material properties are briefly presented in the following sections.

Dune Sand

The investigation was mainly concerned with the utilization of dune sand which is available in abundant quantities in desert areas. The dune sand material was brought from Al-Shimasy area about 40km west of Makkah, Saudi Arabia. The dune sand is composed of sub-rounded to sub-angular grains with smooth texture. The grain size distribution curve for the Shimasy dune sand is shown in Fig. 1. It is mainly a one size material with a range of particle size of 0.40 to 0.075mm. Hazen's uniformity coefficient (Cu) is about 2.38 and coefficient of curvature (Cz) is 0.99. The specific gravity (AASHTO T:100) is 2.76. The standard compaction test (AASHTO T:99-81) gave maximum dry density of 1.66 gm/cc (16.30 kN/m^3) with a corresponding optimum moisture content of 14.8% (Fig. 2).

The physical test results indicated that the dune sand material used in this study is A-3(0) group of AASHTO classification system (AASHTO M 145-49) which is considered to be a non-plastic fine sand with excellent to good possibilities for embankment performance.

The major mineral composing the Shimasy dune sand as analysed by x-ray diffraction is crystalline silica (quartz). Plagioclase feldspar (albite) and alkali feldspar (orthoclase) were also found as minor minerals.

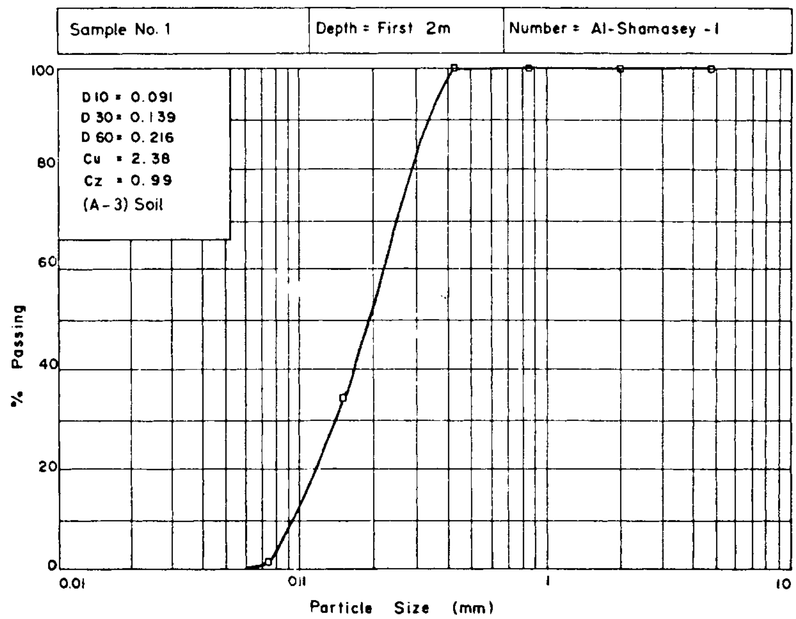

FIG. 1. Grain size distribution and gradation characteristics of Al-Shimasy dune sand.

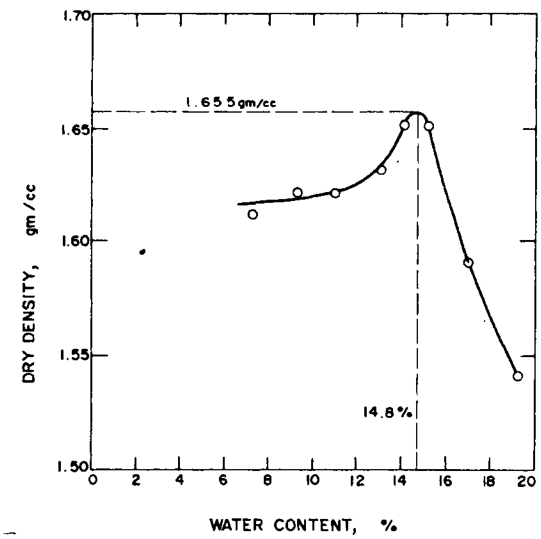

FIG. 2. Dry density-water content relationship of Al-Shimasy dune sand.

Asphalt Cement (AC)

The bitumen used throughout this study was an asphalt cement penetration grade 60/70 (AR-4000). This asphalt grade is believed to be the most suitable for arid regions, where most sand dune areas are located. The asphalt cement was supplied by Petromin-Jeddah. Its specific gravity is 1.025.

Iron Oxide

From Jeddah Steel Rolling Mill Company, the encrustation scrap of rolled steel bars, which is regularly produced as a waste by-product, was obtained and pulverized easily to pass ASTM Sieve No. 200. It was also identified through x-ray diffraction (XRD) for its mineral constituents. It was found to be mainly composed of oxides of iron as shown by the XRD trace (Fig. 3). A scanning electron micrograph is presented in Plate 1.

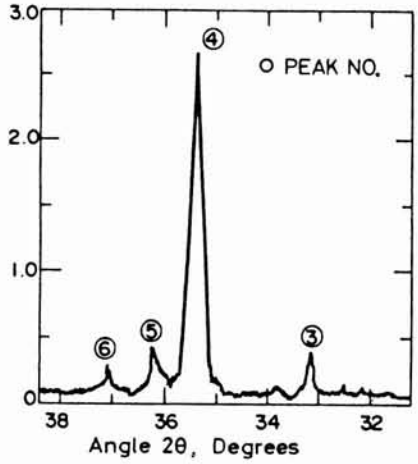

FIG. 3. X-ray diffraction trace of powdered iron oxide.

PLATE 1. Scanning electron migrograph of iron oxide powder (magnification 1:2000).

Portland Cement (AC)

Ordinary Portland cement (Type-I) manufactured locally was obtained and used in the study.

Cement Kiln Dust

The cement kiln dust was obtained from Saudi Cement Manufacturing Company at Rabigh near Jeddah. This dust is a waste by-product and is produced in the form of fine powder in substantial quantities. It could be employed in stabilizing weak dune sand mixes with its possessing filling and bonding properties. The properties of the dust are shown in Table 1.

TABLE 1. Properties of cement kiln dust.

Chemical Analysis			
Loss on Ignition:	26.00%	Free CaO	5.33%
SiO_2	13.94%	Cl^-	2.48%
Al_2O_3	4.74%		
Fe_2O_3	2.36%		
CaO	45.90%		
MgO	2.15%	(Specific gravity: 2.88)	
SO_3	2.14%		
Na_2O	1.03%		
K_2O	1.71%		

Volcanic Tuff Dust

The volcanic tuff classified geologically as SCORIA which is considered a vesicular, cindery, dark lava formed by the escape and expansion of gases in basaltic or andesitic magma, was obtained from local sources nearby Madinah, Saudi Arabia. The dust was obtained by crushing and grinding the light weight fragments of tuff to passing ASTM Sieve No. 200 size. The specific gravity was found to be 1.75. On account of its being fragile and porous, crushing was done easily.

Testing Procedures

The resistance to plastic flow of bituminous mixtures using Marshall apparatus (ASTM D 1559) is considered to be the most widely used method for bituminous mix design. This test is relatively simple and has wide use in the asphalt paving industries. For these reasons, this test was chosen for the evaluation of the dune sand additive mixes. The details of the testing program are presented in Table 2.

TABLE 2. Testing program details.

Series No.	Description	Objective
I	Dune Sand Asphalt Mixes	To find optimum AC content.
II	Dune Sand Asphalt Iron Oxide Mixes	To find optimum iron oxide content for various asphalt contents.
III	Dune Sand Asphalt Iron Oxide Cement/Gypsum Mixes	To study the effect of cement and/or gypsum on the dune sand asphalt iron oxide mixes.
IV	Dune Sand Asphalt Volcanic Tuff Dust and Gypsum Mixes	To study the effect of volcanic tuff dust alone and in the presence of gypsum on dune sand asphalt mixes.
V	Dune Sand Asphalt Kiln Dust Gypsum Mixes	To study the effect of kiln dust alone and with gypsum on dune sand asphalt mixes.

Results and Analysis

Dune Sand Asphalt Mixes

As expected of the behavior of dune sand asphalt mix to be a weak and unstable mix, the Marshall stability reached only 32 kgf (0.31 kN) at asphalt content of 5 percent by total weight of mix (Fig. 4). This mix, in no circumstances, is suitable for base courses at normal traffic and environmental conditions. It should be upgraded to reach the Asphalt Institute requirement of 227 kgf (2.22 kN). Other Marshall design characteristics would not be discussed since stability requirement was not met. Different waste materials/additives taking into account their nature and/or availability with minimal processing costs, were therefore to be tried.

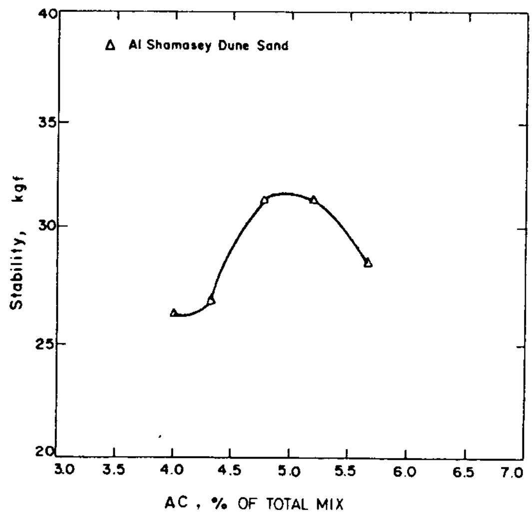

FIG. 4. Stability of the dune sand asphalt mixes.

Dune Sand Asphalt Iron Oxide Mixes

Figure 5 shows the effect of iron oxide addition on Marshall stability of dune sand asphalt mixes in which various proportions of iron oxide were investigated for different percentages of asphalt. The iron oxide content ranged from 0-50 percent of the binder, whilst the asphalt contents were 4 to 6 percent of total mix. It was found that with 4.5 percent asphalt and 10 percent of iron oxide, optimum value of Marshall stability was found to be 77 kgf (0.75 kN) which is less than the design requirement of 227 kgf (2.22 kN). Since the stability requirement was not met, the mix was considered to be weak and hence, the other properties such as flow, percentage voids were not discussed.

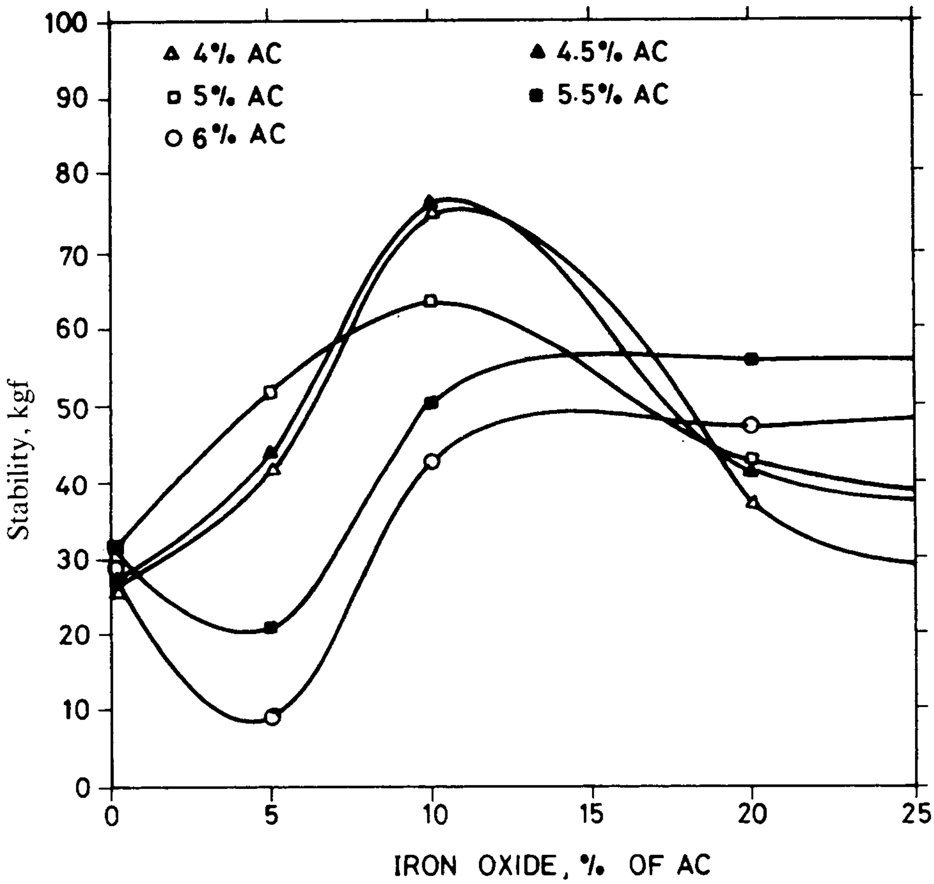

FIG. 5. Effect of iron oxide additions on stability of dune sand asphalt mixes.

Dune Sand Asphalt Iron Oxide Cement/Gypsum Mixes

In order to improve the stability of dune sand asphalt iron oxide mixes, ordinary Portland cement was added in the proportions (0.5%-4.0%) by weight of total mix, with 4.5% asphalt and 10% iron oxide as optimised earlier. The results were not much encouraging as maximum stability value was found to be only 70 kgf (0.69 kN) at 4 percent cement. It was, thus, planned to mix 4 percent cement with dune sand and using a water/cement ratio of 0.40, the mixture was cured for: (a) 30 minutes and (b) 3 hours. Test was carried out to determine the suitable time of curing the dune sand cement mixture before mixing it with the asphalt and iron oxide. The results showed a slight increase in stability from 78 kgf (0.77 kN) to 86 kgf (0.84 kN) when curing time was increased from 30 minutes to 3 hours. But, still the stability values were much below the required limit.

Additional trial mixes were investigated by using 2 percent cement along with 2 percent gypsum and 4 percent gypsum by weight of total mix respectively. The 4 percent gypsum added to dune sand with 4.5 percent asphalt and 10 percent iron oxide gave stability of 192 kgf (1.88 kN) versus 110 kgf (1.08 kN) stability when 2 percent cement was used in conjunction with 2 percent gypsum. Again, the values were lower than the design specifications. At this stage, it was felt necessary to explore the effect, if any, of iron oxide addition to the cement or gypsum added-dune sand asphalt mixes. But the results showed that 4 percent cement mix gave 93 kgf (0.91 kN) stability, and 4 percent gypsum mix gave 190 kgf (1.86 kN) stability (slightly higher than in the case of iron oxide added mixtures). Since, all of these values were lower than the desired, it was, therefore, necessary to explore some other improving agents for the dune sand asphalt mixtures. In this series, however, it was found that gypsum is more effective as compared to cement in increasing the stability in the short term, due to the quick setting process of gypsum.

Dune Sand Asphalt Volcanic Tuff and Gypsum Mixes

Figure 6 shows stability of dune sand asphalt mixes added with volcanic tuff dust alone and volcanic tuff dust mix with gypsum. The dust percentages ranged between 0.5 percent and 20 percent by weight of dune sand. Gypsum was added to various mixes as 2 percent and 4 percent by weight of total mix.

In all of these mixes, 4.5 percent asphalt cement by weight of total mix was used as determined and discussed earlier. The gypsum added mixtures had a water/gypsum ratio of 1.0 and were cured at room temperature for a period of 30 minutes as determined experimentally. The results showed marked improvement in stability (Fig. 6) on account of pozzuollanic effects of tuff dust addition to dune sand by which increase in stability occurs with increasing rate. At 10 percent or higher addition of dust alone, the stability meets the Asphalt Institute requirement fo 227 kgf (2.22 kN). With 2 percent gypsum addition, 7 percent or higher dust contents are satisfying the design limit, with 4 percent gypsum, an addition of 4 percent of volcanic tuff dust or greater would meet the design requirements of Marshall stability. It was also noticed that there is no peak but as the amount of additives increases, the stability keeps on increasing.

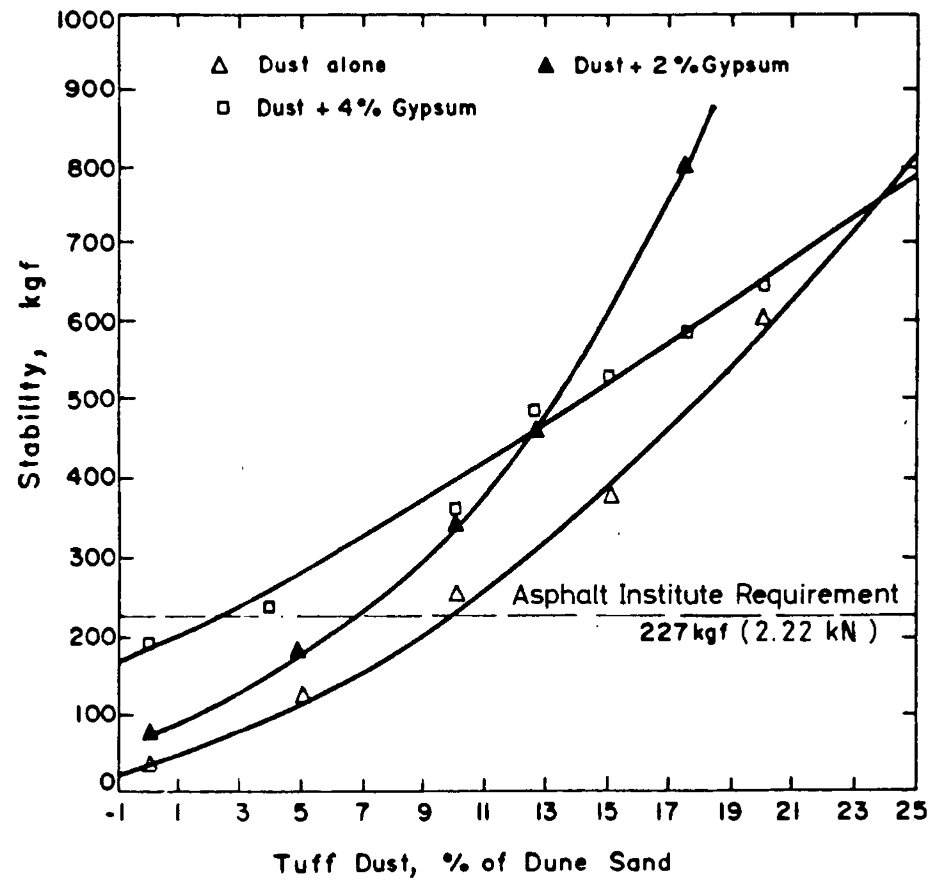

FIG. 6. Effect of tuff dust addition on stability of dune sand asphalt mixes with and without gypsum addition.

The percentage of voids in the mix was in the high range of 16-26 percent due to the uniform grading of the dune sand. Likewise, the voids in the mineral aggregates ranged between 25 to 35 percent, and the unit weights range was 1.82 gm/cc (17.85 kN/m^3) to 1.95 gm/cc (19.13 kN/m^3). Flow values in 0.01 inch (0.25mm) units were in the range of 9 to 14. Thus, the mix is considered suitable for asphaltic pavement base course.

Dune Sand Asphalt Kiln Dust Gypsum Mixes

Kiln dust is obtained as a cheap waste by-product during cement manufacturing process. Like volcanic tuff dust, series of investigations were run to improve dune sand asphalt mixes by using kiln dust from 0-20 percent by weight of dune sand. In other series, 2 percent to 4 percent gypsum by weight of total mix, were added. The water/gypsum ratio was kept to be the same as 1.0, and gypsum added dune sand kiln dust mixes were cured for 30 minutes, and the asphalt cement was added and mixed. The stability data of various test series is presented in Fig. 7. It may be seen that Marshall stability requirements of dune sand asphalt mixes are met with kiln dust contents of 11 percent or more by weight of dune sand. With 4 percent gypsum addition, 10 percent or higher dust amounts would also yield satisfactory stability values. In case of kiln dust alone, a clear peak is noted. The peak occurs at a dust content of 15 percent. The kiln dust material, unlike tuff dust, is non-pozzolanic filling up the voids as filler and acts physically leading to optimal value of stability. The peak is recommended to be used for practical purposes. Further detailed investigations may be pursued in this direction. The flow values of various mixes in 1/100 inch (0.25mm) units are all found to range between 9 and 15.7 which are within the specified criteria of 8-20. The percentage of voids within the mix was in the high range of 20-28 percent due to the uniform grading of the dune sand. Likewise, the voids in mineral aggregate range between 33 percent to 37 percent and the unit weight range was 1.82 gm/cc (17.85 kN/m^3) to 1.95 gm/cc (19.13 kN/m^3). Hence, the selected mixes should behave satisfactorily from stability and flow considerations.

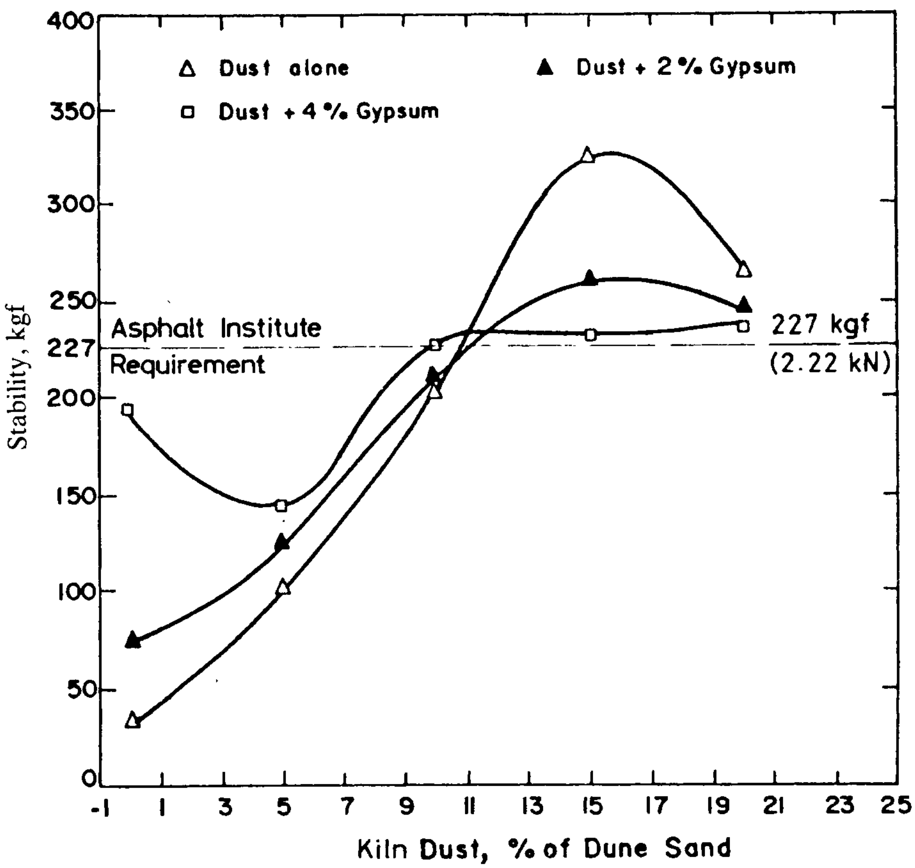

FIG. 7. Effect of clinker dust addition on stability of dune sand asphalt mixes with and without gypsum.

Summary

To summarize, the main findings of this research study are presented as follows:

1. Dune sand asphalt mix showed maximum stability value of 32 kgf (0.31 kN) at an asphalt content of 5 percent by weight of total mix.
2. With 4 percent addition (by weight of total mix) of ordinary portland cement, stability increased to 93 kgf (0.91 kN). Addition of 4 percent gypsum (by weight of total mix) gave optimized stability value of 190 kgf (1.86 kN) at 4.5 percent AC.
3. The addition of 10 percent iron oxide metallic powder (by weight of bitumen) increased the stability to about 77 kgf (0.75 kN). Addition of 2 percent gypsum and 2 percent cement along with 10 percent iron oxide (in proportions as stated earlier) yielded a stability of 110 kgf (0.64 kN) at 4.5 percent AC.
4. The addition of 10 percent or greater volcanic tuff dust by weight of dune sand gave a stability value of 227 kgf (2.22 kN) or more. With the addition of 2 percent gypsum by weight of total mix, volcanic tuff dust contents of 7 percent or more gave 227 kgf (2.22 kN) or more stability at 4.5 percent AC. If gypsum content is increased to 4 percent (by weight of total mix), the dust contents could be reduced to 4 percent (by weight of dune sand) at same AC content.
5. The use of kiln dust from cement industry, yielded promising results. The required stability was accomplished by adding 11 percent kiln dust (by weight of dune sand) at 5 percent AC. The addition of gypsum to kiln dust tended to weaken the mixes at 11 percent kiln dust content or higher.
6. The various mixes utilizing tuff dust and kiln dust had flow values within the permissible limits (8-20). These values ranged between 9-15 in (0.25mm or 1/100 inch) units.
7. The percent voids and the voids in mineral aggregate were in the high side due to the uniform grading of the dune sands. The additives have little effect on these due to their low percentage.

Conclusion

In light of this study it is found that the addition of kiln dust, acting as a filler, does not give satisfactory improvement while tuff dust, acting as a pozzuollonic material, gives good improvement to meet AI requirements. Therefore, dune sand could be utilized using such stabilizer provided other durability test requirements would be met.

Acknowledgement

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Nomenclature

1.	AC	:	Asphalt Cement
2.	AI	:	Asphalt Institute
3.	cc	:	Cubic Centimeter
4.	C_u	:	Co-efficient of Uniformity
5.	C_z	:	Co-efficient of Curvature
6.	gm	:	gram
7.	in	:	inch
8.	kN	:	kilo Newton
9.	mm	:	millimeter
10.	%	:	Percent
11.	θ	:	X-ray diffraction angle
12.	kgf	:	kilogram force

تحســين خلــطات الرمــل الكثيـبي الزفـتي لأساسات الرصــف

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تهتم معظم المناطق في العالم بنضوب الركام المعدني وبالتالي تنظر إلى بدائل أخرى . والمناطق الصحراوية أكثر هذه المناطق حاجة إلى المواد الصالحة لبناء الطرق . لذا ، فإن الاختيار إما أن يتم بتحسين خصائص الرمل الكثيبي وإما باستجلاب المواد اللازمة من مناطق أخرى .

وتعتبر معظمُ مخلفات المصانع نفاياتٍ مكلفةً في نقلها والتخلص منها بالإضافة إلى الأضرار البيئية التي تسببها .

ويدرس هذا البحث إمكانية الاستفادة من استخدام مثل هذه المخلفات في تحسين الرمل الكثيبي لاستخدامه في خلطات طبقات أساسات الرصف الزفتية ، ويعتبر أكسيد الحديد وغبار الفرن الأسمنتي ضمن هذا التصنيف . وقد أدى خلط مواد طبيعية كغبار الطَّفَّة البركانية مع الرمل الكثيبي الزفتي إلى تَحسُّن جيد .

وقد أُضيف الأسمنت البورتلندي والجبس بنسب مختلفة مع الإضافات الأخرى للوصول إلى الحد الأدنى المطلوب للتصميم من قبل معهد الازفلت الأمريكي .

وقد أظهرت النتائج أن الغبار الفرني الأسمنتي وغبار الطَّفَّة البركانية كليهما حققا المتطلب الأدنى لثبات الطرق ذات المرور المنخفض .