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Evaluation of foamed sulfur asphalt stabilized soils for road applications

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HIGHLIGHTS

- Design of marl, sabkha and sand foamed sulfur asphalt (FSA) mixes.
- Evaluate soils-FSA mixes.
- Compare with the conventional foamed asphalt (FA) soils mixes.
- FSA mixes displayed a significant improvement in ITS, stability and shear strength.
- FSA can be used successfully to construct road bases from marginal soils.

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ABSTRACT

This paper summarizes the research carried out to evaluate and compare the performance of marginal soils, namely marl, sabkha and dune sand treated with foamed sulfur asphalt (FSA) with the mixes of the same soils treated with conventional foamed asphalt (FA) for the construction of road bases. FSA and FA mixes were designed for the three soils utilizing low percentage of Portland cement (2%) and were optimized to meet dry and wet indirect tensile strength (ITS) requirements. Designed mixes were evaluated for Marshall stability, static triaxial (shear strength) and dynamic resilient modulus at 22 °C.

Results indicate that properly designed FSA mixes displayed a significant improvement in ITS (17% for marl and 9.4% for sand soils), Marshall stability (14% for marl and sand soils) and shear strength (135%, 76% and 250% for marl, sabkha and sand soils, respectively) as compared with those of conventional FA mixes. Resilient modulus testing indicated that FSA has marginally reduced the resilient modulus of soils compared with FA. Foamed sulfur asphalt technology can be used successfully to construct road bases from available marginal soils.

1. Background

Many parts of the world, where desert and semi-desert environment prevails, lack the good quality road construction materials. One of the typical examples of such environment is the Arabian Gulf and coastal areas of the Red sea. Due to the rapid growing population and expansion of industrial facilities, huge industrial cities and associated network of roads and airports have been being constructed. The scarcity of good quality soils has led to the increased construction cost of road projects which in turn increased the need to look for alternative methods to improve the quality of the huge marginal soils available in these environments to be used in construction projects through soil stabilization. Several soil treatment stabilizers have been used including cement, lime, asphalt, cement kiln dust, fly ash, acids, enzymes, polymers, ion-modifiers, etc. [1–4,10]. Using soil stabilization is to improve the engineering properties of the soil in order to fulfill the project specifications for the intended use.

The basic idea of asphalt foaming is to inject a small quantity of cold water (usually with a mass ratio of 1–5% to the asphalt binder) together with compressed air into hot asphalt (140–180 °C) in a specially designed chamber (Fig. 1). The introduction of water causes an immediate volume increase of hot asphalt due to the increase in its surface area. Water also temporarily lowers asphalt viscosity and improving uniform coating of aggregate and mixture workability. The purpose of asphalt foaming is to make it easier for asphalt to disperse into cold granular materials at ambient temperature. Foamed asphalt technology was developed more than 30 years ago [5,6], but it did not gain much acceptance or implementation after its development, mainly because the required equipments were not available at that time to produce or apply the product on a commercial scale. Recently, due to the advantages

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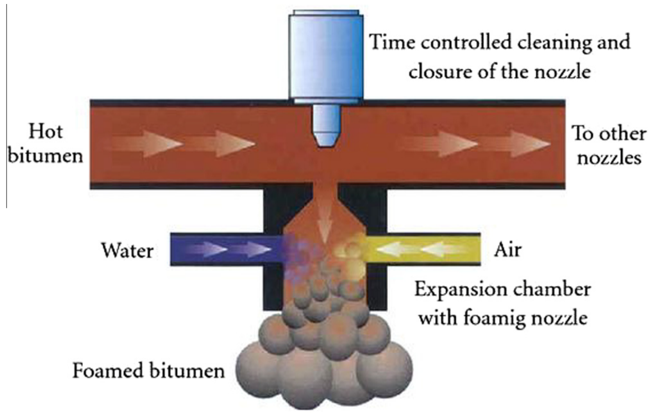

Fig. 1. Asphalt foaming process [22].

of foamed asphalt technology in improved aggregate penetration, coating capabilities, handling, and compaction characteristics, it has progressively gained acceptance as an efficient and economical construction materials improvement and stabilization technique. Saudi Arabia used foamed asphalt application in 1997 in Shaybah oilfield road. Foamed asphalt was formulated using local asphalt cement and used environmentally friendly and cost-effective solutions for road building [5,6,9,10,14].

Sulfur is a by-product of oil and gas production and its rate of production is increasing rapidly every year. Saudi Arabia is one of the largest producers of the sulfur, for example, Saudi Aramco produces sulfur at a rate of approximately 6000 ton/day and it is expected to increase to 10,000 ton/day in few years [12]. Although sulfur is a vital raw material to manufacture a myriad of products, its abundance reduced its price worldwide. Sulfur asphalt has proven its advantage when used to build local roads and was used to reduce the required asphalt cement up to 30% with no short-term or long-term environmental hazards as indicated by the low emission of hazardous gases at road surface temperature as high as 76 °C prevailing in Saudi Arabia [15,5,12].

Foamed asphalt technology has been successfully employed in Europe, Africa, and Middle East since the late 1980s and is being increasingly adopted in the U.S., Canada, and Australia as its benefits become widely known [13,16,18,19,21].

Asi et al. [9,10] carried out several laboratory studies to evaluate the possibility of using foamed asphalt technology in Saudi Arabia to improve the dune sands or sabkha soils for possible use as a base or subbase material in comparison to emulsified asphalt treatment. Several variables were investigated to evaluate the relative improvement of local soils as well as to permit the development of design procedures for the future use of foamed asphalt technology in the harsh climatic conditions of eastern Saudi Arabia. The results were statistically analyzed and employed to verify the effects of foamed asphalt treatment, with and without the addition of Portland cement, on the strength characteristics of the treated mixes. Based on the results displayed, a significant improvement was noticed in the performance of foamed asphalt mixes, as compared to that of the emulsified asphalt mixes.

Al-Abdul Wahhab et al. [6] have investigated and evaluated the feasible use of foamed asphalt technology for Saudi roads using marginal quality construction materials, marl, and reclaimed asphalt pavement (RAP) materials for local applications. Foamed asphalt mixes were designed for subbase class B (foamed SB) and reclaimed asphalt pavement (foamed RAP) material utilizing low percentage of Portland cement. They optimized the foamed asphalt mixes to meet dry and wet indirect tensile strength (ITS) requirements. Designed mixes in addition to granular base class A and B were evaluated for CBR, dynamic resilient modulus at 25 °C and wheel tracking test dry at 50 °C and soaked at 22 °C. The results of this study indicated that Portland cement was effective in reducing ITS loss of foamed asphalt mixes. Resilient modulus testing indicated that SB mix has behavior comparable to base class A. Foamed RAP mix has shown the best behavior. Saturation has reduced resilient modulus of all mixes significantly. Finally they concluded that foamed asphalt technology can be used successfully to construct road bases from locally available marginal or recycled materials.

Baig et al. [12] investigated the feasibility of using sulfur as an additive for local asphalt concrete mixtures at KFUPM. They also studied many cases of using sulfur modified asphalt in road construction including the field trial at Khursaniyah and the concerns related to air pollution due to sulfur containing gases. They concluded that, it will be no constructability problem with the use of sulfur and the use of asphalt with sulfur material at 30% replacement could be more economical as compared to regular asphalt. Furthermore, the results of field tests indicated that there is no long-term hazard for mixes as showed by acceptable values of emission of hazardous gases such as H_2S and SO_2 (<1 PPM at 76 °C). However, precautions must be taken during the laying of mixes at 145 °C.

In this study, laboratory tests were carried out to investigate the possibility of producing and using 30/70 sulfur modified foamed asphalt for improving the mechanical properties of marginal soils, namely, marl, sabkha and dune sand for road applications. Sulfur was used to reduce the binder content of foamed asphalt by up to 30%.

2. Experimental work

Marginal soils cover most areas of the eastern province of Saudi Arabia. In order to investigate the possible treatment of these marginal soils, required quantities of dune sand, marl and sabkha soils were collected, subjected to basic characterization and then stored for the use in the experiments. The basic engineering properties of the soils were assessed by conducting preliminary characterization tests including mineralogical analysis, specific gravity, plasticity tests and grain size distribution. In addition, the compaction and strength characteristics were investigated by using modified Proctor compaction and California bearing ratio tests.

Asphalt cement was collected from the Saudi-Aramco Ras-Tannurah refinery, subjected to basic characterization and then stored for the use in the experiments. The grade of the utilized asphalt was 60/70 penetration, since this grade is the only virgin asphalt grade that is widely used in all road projects in the Kingdom. Several ASTM tests were conducted on asphalt cement to evaluate its basic physical properties such as, viscosity, penetration, softening point, flash point and ductility.

Laboratory mix design procedure was carried out based on the cited literature [22] as outlined in the Writgen Cold Recycling Manual and summarized in Fig. 2.

Designed foamed sulfur asphalt mixes which include marl, sabkha and dune sand in addition to the mixes of these soils with conventional foamed asphalt were subjected to indirect tensile strength (ASTM D 4867), Marshall stability (ASTM D 1559), dynamic resilient modulus (MR) (AASHTO T-307), and static triaxial (ASTM D 2850) to evaluate their engineering properties.

3. Results

3.1. Materials characterization

3.1.1. Mineralogical analyses of soils

X-ray diffraction (XRD) technique was used to perform the mineralogical composition of the marl, sabkha, and sand soils used in this study. XRD analyses for these soils are shown in Figs. 3–5.

Fig. 3 shows the X-ray diffractogram for marl and the peaks reveal the presence of about 60% dolomite [$CaMg(CO_3)_2$], 30% quartz (SiO_2) and 6% calcite ($CaCO_3$) in addition to traces of other minerals. The relatively high percentage of calcite and quartz is responsible for the non-plastic and fine–grained nature of this type of marl [8].

The X-ray diffractogram for sabkha soil is shown in Fig. 4. Peaks for quartz (75%), gypsum (12%) and halite (10%) were noted in