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Incorporation of Jordanian oil shale in hot mix asphalt

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ABSTRACT

Many projects utilizing oil shale for power generation and shale oil extraction are being investigated, developed, or built due to an increase interest in utilizing this source of energy. It is expected that this evolving industry will produce large quantities of oil shale waste particles having very fine sizes which are considered both harmful to the environment and a loss of a valuable resource. This investigation is considering to address both of these two negative expectations by incorporating the above fine oil shale particles into hot mix asphalt (HMA) pavement formulations. Different compositions of oil shale in the new asphalt pavement mixtures were investigated in accordance of local highway regulations. The results of this work are very promising. For example, Marshall stability showed an improvement by 10–20%. All required properties by Jordanian highway regulations (which are, in general, based on American Association of State Highway and Transportation Officials, AASHTO) such as flow, voids in mineral aggregates and air voids have been either satisfied or even improved. In addition, resilient modulus, creep and fatigue tests were performed on some formulations. The major findings of these tests indicate that HMA containing only limestone is more resistant to rutting in the short run however; it loses its strength as it ages. On the other hand, HMA containing oil shale is not as much resistant to rutting in the short run; however, it retains its flexibility in the long run (more fatigue resistance). Finally, the environmental investigation of the impact of using oil shale in HMA pavements indicates that there are no negative impacts on the environment with respect to leaching and radioactivity.

1. Introduction

Jordan ranks among the top ten countries in the world with respect to oil shale resource estimates (Besieso, 2007; Kiliç et al., 2014). Jordan's supply of energy depends heavily on imported oil and natural gas. Oil shale is considered a major possible alternative source of energy in Jordan which; according to Jordan National Energy Research Center and others; has an estimated more than 50 billion tons of geological proven reserves of oil shale that is widely distributed all over the country (Hamarneh, 1998; Knaus et al., 2010; Kiliç et al., 2014).

Oil shale is a layered sedimentary rock that contains significant quantities of kerogen. Jordanian oil shale is mainly composed of calcium compounds (calcium carbonate content is about 40–70%), in addition to sulfur compounds (around 3%), organic matter (total organic matter is about 20%), silicon compounds (around 5–25%). When heated to temperatures above 482 °C, the kerogen in the shale decomposes producing shale oil, gas and spent shale. The average oil content of oil shale is generally in the range of 5–15% (Hamarneh, 1998; Knaus et al., 2010).

One way of making use of oil shale is by direct combustion of oil shale from mining sites to power plants in the same way as coal. This is being done for example in Estonia which has one of the highest grade deposits in the world with an average heating value of about 8.3 MJ/kg (Arro et al., 2003; Altun et al., 2006). This method generates fine sizes of particles of oil shale causing environmental concern.

Another method of benefitting from oil shale is the extraction of shale oil from oil shale. Many investigations have been done and are still being done on this method (Ogunsola and Berkowitz, 1995; Ga-Hourcade et al., 2007; Allawzi et al., 2011; Al-Gharabli et al., 2015). There are also several technologies used in demonstration projects

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Nomenclature

AASHTO	American Association of State Highway and Transportation Officials
CNF	Carbon nanofibers
CNT	Carbon nanotubes
EDX	Energy-dispersive X-ray spectroscopy
H	High
HMA	Hot mix asphalt
ICP	In-situ conversion process
L	Low
M	Medium
MCA	Multi-channel analyzer
MR	Resilient modulus
OAC	Optimum asphalt content
OSEC	Oil Shale Exploration Co.
PMT	Photo-multiplier-tube
RAP	Recycled asphalt pavement
RD&D	Research, Development & Demonstration
SEM	Scanning electron micrograph
TGA	Thermo-gravimetric analysis
VMA	Voids in mineral aggregate
XRD	X-ray diffraction
XRF	X-ray fluorescence
%Va	Percentage air void

in the USA, Estonia, China, and other countries to recover shale oil and gas from oil shale deposits (Bussell, 2009) such as the underground mining and surface retorting (used by OSEC – Oil Shale Exploration Co. and in situ conversion process (ICP) using self-contained heaters (used by Shell).

A third way of using oil shale is to incorporate it in the cement and concrete industry. For example, Al-Otoom (2006) has reported a reduction in the required cement clinkering reactions temperature when oil shale was added to the clinker mixture during production, and hence a potential cost reduction in the production of Portland cement, however CO_2 emissions might be of concern to this practice. In another investigation by Smadi and Haddad (2003), spent oil shale that resulted from a retorting operation at 600 °C was added to concrete mixes, which did not affect mechanical properties significantly. Similar results were also found by adding oil shale ash to Pozzolanic cement (Khedawi et al, 1990).

A fourth way of benefitting from oil shale is to incorporate it in asphalt pavement mixtures, which is the subject of this work. Several investigators studied the effect of employing shale oil (not oil shale) in asphalt and/or asphalt pavement mixtures. For example, Mahboub et al. (1992) conducted a feasibility study to establish possible paving applications of oil extracted from eastern shale (Kentucky, USA) by the KENTORT II process. They concluded that depending on the viscosity of employed shale oil the asphalt properties exhibited desirable or undesirable behavior. The authors of the study recommended further studies to fully characterize the binder and mixture properties of investigated shale oil. In another study, Thomas et al. (1996) made a comparative field assessment of shale oil-modified asphalt with polymer-modified asphalts. They concluded that even though the properties were comparable, the cost of the shale oil-modified asphalt was much lower.

Katamine (2000) on the other hand, investigated the rheological properties of conventional asphalt binder in comparison to the same binder but modified with shale oil obtained from Jordanian oil shale. The study concentrated on evaluation of deformation resistance of hot mix asphalt using Marshall design method and the immersion wheel tracking machine. The study concluded that the shale oil binders should be treated before being used because they displayed inconsistent physical properties. In addition, Katamine indicated that the oil shale fillers have increased deformation resistance of hot mix asphalt while the deformation resistance decreased with increasing oil content of oil shale fillers.

Regarding the subject of hot mix asphalt (HMA) pavement investigations, the literature is rich of varieties of research conducted in this area. For example, aggregate replacements; such as cement kiln dust, coal waste powder and waste glass (Modarres et al., 2015a,b; Arabani and Kamboozia, 2013) were investigated. Others have investigated the use of industrial wastes or recycled waste materials; such as paper industry wastes, recycled concrete and recycled bricks (Pasandín et al., 2015a,b; Gul and Guler, 2014; Chen et al., 2011); into the aggregate, or recycled asphalt shingles, waste plastics or reclaimed asphalt binder, into the asphalt binder (Miliutenko et al., 2013; Abbas et al., 2013; Köfteci et al., 2014; Zaumanis et al., 2014). One investigation even considered using sludge waste in HMA (Al-Ghazawi et al., 2008). Other investigations were concerned with asphalt binder modified with polymers; such as polyethylene, polyethylene terephthalate, and ethylene vinyl acetate (Napiah et al., 2014; Moghaddam et al., 2014; Ameri, 2013), or non-polymeric materials; such as bio-oil and monoethylene and diethylene glycols (Yang and You, 2015; Arslan et al., 2014), and more recently with nano-materials; such as carbon nanotubes (CNT), carbon nanofibers (CNF), nanoclays, nanosilica and nano-titanium dioxide (Arabani and Faramarzi, 2015; Shafabakhsh et al., 2014; Khattak et al., 2013; Yao et al., 2012, 2013). Some investigations were even done on improving the testing methods of HMA (Khosla and Ayyala, 2013; Feng et al., 2013; Rahmani et al., 2013), or on the interpretations of the results of such tests (Aflaki and Memarzadeh, 2011), or on HMA mixing process conditions (Pérez-Jiménez et al., 2014).

Jordan is currently moving ahead with major projects that are to exploit the national treasure of oil shale (projects with JOSCO and Enefit companies). During the mining process of oil shale, some of these projects are expected to produce very fine particles of oil shale. Some of these fine sizes are considered as environmental and health hazards. One key solution to these expected hazards is to incorporate these harmful sizes of oil shale powder into HMA pavements.

The objective of this work was to study the effect of replacing limestone filler aggregate of HMA pavement with oil shale filler. The investigated parameters were Marshall stability and flow, air voids, voids in mineral aggregates, resilient modulus, creep and fatigue. In addition, an assessment of the environmental impact of incorporating oil shale filler size into HMA was made.

2. Materials and methods

2.1. Asphalt cement

The binder used in this investigation was produced by Jordan Oil Refinery Company. The asphalt binder penetration grade was 60/70. Table 1 shows a summary of its properties as measured in this work. In addition, Table 1 also states the ASTM test methods followed in conducting these measurements.