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APPLICATION OF NANOTECHNOLOGY IN PAVEMENTS, GEOLOGICAL DISASTERS, AND FOUNDATION SETTLEMENT CONTROL TECHNOLOGY

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Preface

Although improvement in asphalt performance have been achieved through chemical modification, it will be interesting to explore what nontechnology offers in improving asphalt pavement performance. Nanotechnology is the study of the control of matter on an atomic and molecular scale. This technology has the potential to create many new materials and devices with wide-ranging applications in medicine, electronics, and energy production. The utilization of nontechnology in civil engineering area is relatively new and its use and applications are expected to increase rapidly. In spite of advancement s in pavement engineering, there are several transportation issues still remain unsolved in developing nations. Many technology and techniques have been developed recently to control geological disaster and foundation settlement. The civil engineering infrastructure engineers have been working widely to find out a viable and cost effective solution for such problems.

This Geotechnical Special Publication contains papers that were accepted and presented at the GeoHubei 2014 International Conference on Sustainable Civil Infrastructures: Innovative Technologies and Materials, held in Yichang, Hubei, China, July 20 to 22, 2014. The four major topics covered are:

- Nano Technology and Its Application to Civil Infrastructure
- Transportation Issues in Developing Countries
- Geological Disaster Control Technology
- Special Foundation Treatment and Settlement Control Technology

The editors would like to thank the many individuals who assisted in reviewing the abstracts and papers. Without their efforts we would not have had high quality papers included in this publication.

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Evaluation of Moisture Susceptibility of Nanoclay-modified Asphalt Binders

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ABSTRACT: Due to an increasing rate of traffic volume and truck loads in recent years, neat asphalt binders are often modified with expensive polymers for increased stiffness. Nanoclays, on the other hand, are relatively inexpensive and naturally abundant, and have favorable intrinsic properties (e.g., nanoscopic size and surface area). Although the stiffness of nanoclay-modified binder is reported to increase, its moisture resistance remains unknown. To this end, the current study investigated moisture resistance of a performance grade binder (PG 64-22OK) modified with different dosages of a selected nanoclay (Cloisite® 15A) through the surface free energy (SFE) technique. The state of dispersion of the nanoclay in the binder was examined using scanning electron microscope and small angle X-ray diffraction (SAXD) techniques. The cohesive energy of nanoclay-modified binder was found to be lower than that of the base binder. The adhesive energy between eight different aggregates (sandstone, gravel, granite, basalt, and limestone from four sources) and 2% nanoclay-modified binder in dry condition decreased up to 22%. The adhesion energy in wet condition reduced up to 24%. The compatibility ratio (CR) values of different aggregates with the nanoclay-modified binders show significant decrease in bond strength in cases of all aforementioned aggregates except granite.

INTRODUCTION

Over 90% of paved roads in the U.S. are asphalt pavements, and the annual expenditures for the maintenance of these pavement infrastructures exceed $100 billion (NECEPT 2012). Although a small amount (about 5%), asphalt binder plays a major role on the performance of the hot mix asphalt (HMA) pavements. Now-a-days, polymer additives (e.g., styrene-butadiene-styrene (SBS)) are used to enhance mechanistic properties such as increased rut and crack resistance of asphalt binders. The addition of polymers increases the overall cost of asphalt binders and mixes. On the other hand, nanoclays posses an extraordinary potential for improving the performance of asphalt binder and asphalt mixes due to their nanoscale phenomena such as the quantum effects, structural features, high surface energy, spatial confinement and large fraction of surface atoms. Moreover, nanoclays are fairly inexpensive, naturally abundant and sustainable materials for the construction of asphalt pavements. Thus, a significant portion of the current usage of polymer-modified binders can potentially be replaced by nanoclay-modified binders for improved mechanical and functional characteristics of the asphalt pavements.

Nanoclays are layered silicates that are found naturally and hence they are environmentally safe, economical, and sustainable. One of the most frequently used layered silicates is montmorillonite (MMT), which has a 2:1 layered structure with two silica tetrahedron layers sandwiching an alumina octahedron layer. These three layers together form one clay sheet that has a thickness of about one nm (one-billionth of a meter), thus the individual clay sheets are classified as "nanomaterial," although the lateral dimensions of the individual clay sheet can vary from 100 nm to a few microns with unusually high aspect ratio (NNI, 2013). On the other hand, a portion of fine-grained soil that consists of one or more clay minerals (e.g., hydrous aluminium phyllosilicates) with traces of metal oxides and organic matter which is finer than 0.002 millimeter.

A number of physical, mechanical and rheological properties of polymer binders are successfully enhanced by the addition of a small amount of nanomaterials, 1-5 percent by weight (Saha et al. 2010). Due to their enormous surface area and energy, nanoclays have huge potential as modifier to improve asphalt binder's performance properties (e.g., rutting). Untreated nanoclay sheets are held together due to high metallic cations presence on the surface, giving a low inter-gallery spacing (about 11.7^{o}A). Organic treatments are often used to increase the inter-gallery spacing so that polymer molecule can penetrate between the inter-gallery spacing of the silicate layers. When the polymer molecules penetrate between the adjacent layers of the nanoclay sheets, the gallery spacing is increased and the resulting morphology is called intercalated structure. An exfoliated morphology occurs when the clay platelets are extensively delaminated and completely separated as a result of through polymer penetration. Schematic of different morphology of nanoclay-polymer structure is shown in Fig. 1. Although various dispersion techniques, in combination with coupling agents, are used, creating an exfoliated nanoclay structure in a stable manner is a challenging task.

Even though the advancement of nanotechnology research has increased in recent years, limited studies attempted to investigate the application in asphalt pavements. You et al. (2011) studied effects of two unspecified nanoclays on a PG 58-34 binder. It is reported that with the 2% nanoclay-modified binder the complex shear modus (G*) increased about 66% while the 4% nanoclay-modified binder the G* values increased by 125%. This study also reported significant increase in viscosity of the nanoclay modified binders. In a study by Jahromi and Ahmadi (2011), it is reported that both the Cloisite15A and Nanofil15 modifications on a viscosity grade AC-10 binder increased the stiffness and rutting resistance, indirect tensile strength, and resilient modulus, but reported decreased fatigue performance. These researchers reported that nanoclay was found to increase the viscosity of the neat binder. However, none of the studies focused on the preparation and mechanistic evaluation nanoclay-modified asphalt binders for conditions (e.g., binder source and grade, climate conditions, and design specifications) prevailing in Oklahoma.

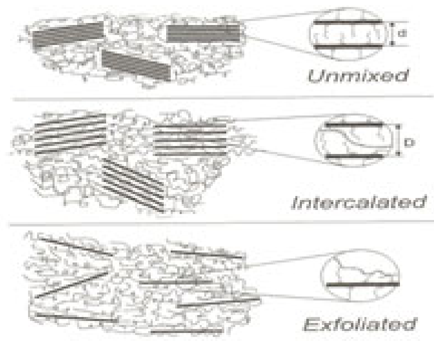

FIG. 1. Various nanoclay morphology produced due to mixing (Koo, 2006).

While some rheological data of nanoclay-modified binders from limited studies (e.g., Hossain et al. 2013) shows positive results, moisture susceptibility of nanoclay-modified binders is yet to be investigated. Traditionally, tensile strength ratio (TSR) data is used to investigate moisture susceptibility of asphalt mixes. However, outcomes of these techniques are often misleading as they lack scientific rigor. Recent studies (e.g., Bhasin et al. 2007) introduced a similar parameter called compatibility ratio (CR) in the surface free energy (SFE) theory, which is based on a surface science approach. The CR is defined as the ratio of work of adhesion of an aggregate and binder system (dry condition) to the work of adhesion of the same system in presence of water (wet condition). The higher the CR value, the higher moisture resistance of the aggregate-binder system is.

Toward evaluating SFE of asphalt binders, Cheng et al. (2001) first proposed the SFE theory and used the Good-van Oss-Chaudhury theory to evaluate the free energies of the asphalt binder and aggregates, and subsequently the free energy of adhesion between them for moisture susceptibility of asphalt mixes. According to the Good-van Oss-Chaudhury theory, the SFE of a material is divided into three separate components based on the source of the intermolecular forces: a monopolar acidic component (Γ^+), a monopolar basic component, (Γ^-) and an apolar, or Lifshitz-van der Waals (Γ^{LW}) component. The total SFE (Γ^{total}) for a single phase is divided into Lifshitz-van der Waals component (Γ^{LW}) and acid-base component (Γ^{AB}).

Several researchers have developed SFE databases for different aggregates and asphalt binders and drawn conclusions on their performance based on the free energy of adhesion. Cheng et al. (2001) used the SFE of the asphalt binder to estimate the wetting ability of aggregates by asphalt binder. Bhudhala et al. (2012) used the protocol proposed by Cheng et al. (2001) to determine the contact angles of asphalt binders, modified with warm mix asphalt and amine anti-stripping agents. In a few other studies, researchers studied the effect of different additives on the cohesive strength of asphalt binders and adhesive strength between asphalt binders and aggregates (e.g., Bhasin et al. 2007). While the tested materials of the current study differs from those of the aforementioned studies, it is emphasized that the SFE and other surface properties follow a complex phenomenon and depend on various factors such as the type of asphalt binder, type of aggregate and the type of additive used.

The main objectives of the proposed study are to prepare nanoclay-modified asphalt binders and to investigate the effects on nanoclays on moisture resistance of the neat asphalt binder. To achieve these objectives, the current study evaluates the effects of dosage levels of a selected nanoclay on surface free energies and compatibility ratios of nanoclay-modified binders.

MATERIALS AND METHODOLOGY

Materials

The current project evaluated a commonly used unmodified PG 64-22OK binder modified with different dosages (1%, 2% and 4% by the weight of the binder) of nanoclay (Cloisite 15A). The PG 64-22OK was obtained from Valero refinery at Ardmore, Oklahoma. Cloisite 15A nanoclay powder was obtained from Southern Clay Products. The Cloisite 15A is a natural montmorillonite modified with a quaternary ammonium salt. The average particle size is about 13 micron with average d-spacing of 31.5 Angstrom. The average density is about 1.66 g/cc.

Mixing Nanoclay and Asphalt Binder

Roughly 175 gm of the neat binder was heated in a glass container to 150^{o}C for about 2 hours to achieve the processing viscosity. Then the nanoclay was added to the heated asphalt binder while slowly stirring the mixture using the magnetic stir bar. The speed was slowly increased and fixed to about 500 rpm while maintaining the mixing temperature of 150^{o}C using a thermocouple connected to the hot plate. The mixing was continued for about 2 hours to achieve uniform dispersion of the nanoclay in the asphalt binder.

Dispersion Characterization

The dispersion of nanoclay in asphalt binders was examined at nanoscale level using both scanning on electron microscope (SEM) and small angle X-ray diffraction (SAXD) techniques. Both SEM and SAXD data are compared to achieve a conclusion on the level of dispersion and efficiency of the blending process. In the SAXD technique, Bragg's law of diffraction is used to measure d-spacing between the nanoclay sheets. Spacing change (increase or decrease) information can be used to determine the type of dispersion. For example, no d-spacing change indicates immiscible, increase in d-spacing indicates intercalated, and no distinct peak in the signal indicates exfoliation.

Effect of moisture on the theoretical bond strength (adhesive and cohesive) was evaluated based on SEF components using using the Good Van Oss-Chaudhury theory (van Oss et al., 1988). A dynamic contact angle analyzer (Fig. 2) was used in this study for measuring the contact angles of asphalt binder with three reference solvents (water, glycerin and formamide). This analyzer follows the Wilhelmy plate method, which determines the contact angle at the solid-liquid interface by measuring the force exerted by the meniscus on the sample.