Evaluating the Rheological Performance of Bituminous Binder Containing Nano Al_2O_3

Faheem Sadiq Bhat[1] and Mohammad Shafi Mir[2]

Abstract: The study reported herein investigates the effectiveness of nano aluminum trioxide (Al_2O_3) as a bituminous binder modifier. The study assesses the high- and intermediate-temperature performance of bituminous binders modified with three different percentages (0.5%, 1%, and 2%) of nano Al_2O_3. A field emission scanning electron microscope was utilized to study the dispersion of nano Al_2O_3 in bituminous binder. Fourier transform infrared spectroscopy analysis was used to understand the nature of the interaction between nano Al_2O_3 particles and bituminous binder. Different rheological approaches, like the Superpave rutting parameter, multiple stress creep and recovery test, and time-temperature sweep, were used to study the high-temperature performance of nano Al_2O_3–modified bituminous binders. All the methods undertaken in the current study to evaluate rutting susceptibility showed that nano Al_2O_3 showed modified binders had a very low propensity to accumulate permanent deformation. Fatigue performance evaluated using the Linear Amplitude Sweep test showed that the incorporation of nano Al_2O_3 enhanced fatigue performance. Nano Al_2O_3–modified bituminous binders were found to be storage stable as revealed by the storage stability test. The high-temperature thermal stability of the bituminous binders measured using thermogravimetric analysis showed an improvement after nano Al_2O_3 incorporation. **DOI: 10.1061/(ASCE)MT.1943-5533.0004088.** *© 2021 American Society of Civil Engineers.*

Author keywords: Nano Al_2O_3; Rutting; Nonrecoverable creep compliance; Fourier transform infrared (FTIR) spectroscopy; Thermogravimetric analysis (TGA); Elastic modification index; Linear amplitude sweep.

Introduction

Bitumen is used in pavement construction as a binder, holding aggregates and other components together. Pavements are subjected to varying magnitudes of loads and different environmental conditions. Load- and non-load-related distresses manifest as different types of failure, such as rutting, fatigue cracking, and thermal cracking.

Unmodified bituminous binders are incapable of withstanding the high stresses caused by increased axle loads and varying environmental conditions. Thus, diverse types of modifiers are used to ameliorate the performance of bituminous binders (Kim et al. 2019; Lu and Isacsson 1997; Lo Presti 2013; Yildirim 2007). A modifier is regarded as quintessential if it can perform appropriately at high, intermediate, and low temperatures (Leiva-Villacorta and Vargas-Nordcbeck 2019). The use of nanomaterials for bituminous binder modification has been found to be effective at addressing various issues related to flexible pavements. Nanomaterials possess some appealing properties, for example, small size, large ratio of surface area to volume, high functional density, and high strain resistance, and these properties can have significant effects on the performance of bituminous binders even when used in small percentages. Compared to fillers and other modifiers, nanomaterials provide a higher specific interfacial area that leads to higher interfacial interactions, leading to higher gains in the modulus (Bhattacharya 2016). The high specific surface area and spatial confinement give nanomaterials better properties than their macroscopic counterparts (Crucho et al. 2019). Nanosilica, carbon nanotubes, nanoclay, graphene, titanium dioxide, and zinc oxide are some of the nanomaterials being investigated for bitumen modification. Reviews by Steyn (2009), Fang et al. (2013), Yang and Tighe (2013), Ashish and Singh (2019), and Calandra et al. (2020) give insights into the present and future prospects of nanomaterial application in binder modification. A large number of studies have found that nanomaterials like nanoclay, nanosilica, carbon nanotubes, graphene and graphene derivatives, titanium dioxide, and nano zinc oxide show adequate improvements in terms of permanent deformation characteristics, fatigue cracking, low-temperature cracking, oxidative aging resistance, thermal stability, and high-temperature storage stability (Ashish et al. 2016; Ashish and Singh 2018; Bhat and Mir 2019, 2021a; Ezzat et al. 2016; Hassan et al. 2011; Jahromi and Khodaii 2009; Leiva-Villacorta and Vargas-Nordcbeck 2019; Li et al. 2017; de Melo and Trichês 2016; Nejad et al. 2017; Saboo and Sukhija 2020; Singh et al. 2017; Wang et al. 2019; Yao et al. 2013; Zhang et al. 2018; Ziari et al. 2014).

Nano Al_2O_3 is a new type of nanomaterial for the construction industry. Its good thermal conductivity, high strength and stiffness, high surface area, thermal stability, mechanical strength, and high wear resistance make nano Al_2O_3 an ideal modifier. It has found widespread application in the cement industry. The use of nano Al_2O_3 has been found to augment various performance characteristics of cement paste and cement concrete. Studies have reported improvements in compressive strength, void number, frost resistance, and resistance to chloride attacks following the addition of nano Al_2O_3 to cement (Behfarnia and Salemi 2013; Chen et al. 2018; Gowda et al. 2017; Štefančič et al. 2017).

Rutting and fatigue are the two main distresses associated with flexible pavements. Limited studies are available assessing the rutting and fatigue performance of nano Al_2O_3–modified bituminous binders. The incorporation of nano Al_2O_3 enhances the stiffness of bituminous binders; improvement in the complex shear

[1]Ph.D. Research Scholar, Dept. of Civil Engineering, National Institute of Technology Srinagar, Srinagar, Jammu and Kashmir 190006, India (corresponding author). ORCID: https://orcid.org/0000-0002-8886-7914. Email: faheem_35phd17@nitsri.ac.in

[2]Professor, Dept. of Civil Engineering, National Institute of Technology Srinagar, Srinagar, Jammu and Kashmir 190006, India. Email: shafi@nitsri.ac.in

Note. This manuscript was submitted on December 2, 2020; approved on June 18, 2021; published online on November 25, 2021. Discussion period open until April 25, 2022; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Materials in Civil Engineering***, © ASCE, ISSN 0899-1561.