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Evaluation of mechanical properties of nano-clay modified asphalt mixtures

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A R T I C L E I N F O

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This study aimed to investigate the performance of nano-clay modified asphalt mixtures. This study aimed to investigate the performance of nano-clay modified asphalt mixtures. Three different nano-clay materials were selected and each modifier was used with three different concentrations (2%-3.5%-5%) as substituted for filler.

Modified Lottman including hot water conditioning (conditioning 1) and cold water conditioning (conditioning 2) systems were used. Models of water damage were used on half of the identical compacted samples. Cracking, stripping and rutting evaluations were realized with AASHTO T 283 Modified Lottman Test and repeated creep tests (RCT) with Nottingham asphalt tester (NAT). Indirect tensile strength (ITS) tests were realized with control and two types of conditioning systems but RCT were applied with control and Lottman water damage procedure. Nano-clay materials increased rutting resistance of samples with Lottman water damage conditioning method. 2%, 3.5% and 5% nano-clay modified mixtures were found as more rutting resistance than the conventional mixtures according to the AASHTO T283 conditioning. Indirect tensile strength tests were realized with Lottman moisture damage conditioning model. Higher tensile strength values were obtained with 2% and 3% nano-clay modified asphalt mixtures denotes that higher internal friction. Stripping damage of the modified mixtures was interrogated with the ratios of tensile strength concept. In the ratios of tensile strength, 2% each of three nano-clay modified mixtures gives higher ratios. Stripping resistance of the 2% nano-clay mixtures was found as higher than the control conditioned samples based on Modified Lottman Test. It is thought that nano-clay modifiers can be successfully used in view of higher stripping, rutting and cracking resistance with low ratio as 2%. Stripping resistance increased with increasing nano-clay concentrations in view of conditioning 2. As a result of the mechanical test approaches 2% nano-clay content is thought as a suitable ratio in context with stripping, rutting and cracking optimization.

1. Introduction

Rutting and fatigue cracking distresses occur mainly before the service life of pavement. The minimizing of the problems would be more economical for recovery, while reconstructing defects would involve more costs. One of the methods is to modify the properties of asphalt cement for avoiding failure. Various methods, such as the use of different polymers types, were employed. Using additives such as nano-materials to improve asphalt cement and mixture performance has recently become more popular. Nano-composites are among used materials for improving asphalt mixture properties [1–4].

Nano-technology is a highly creative and promising technique for the materials industry. Nano-materials find widespread use in many applications around the world. The Scientific Committee on Emerging and Newly Identified Health Risks defines nano-materials as a type of material with an outer structure consisting of one or multiple outer dimensions; an internal structure consisting one or more dimensions in the order of ⩽100 nm; and whose properties differ from those exhibited by comparable materials lacking nano-features. Portland cement with non-materials is being used by many researchers. In recent times, nano-materials have also begun to find use in asphalt pavement mixtures. Nano-technology is being used to develop new materials, devices and systems by modifying and fashioning them at a molecular level. There are various different types of nano-materials available, with each type offering different opportunities for modifying and improving asphalt mixtures. Examples of nano-materials that can

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be used in asphalt applications include nano-tubes, nano-fibres, polymerized powders, nano-sized plastic powders, nano-hydrated lime, nano-silica, and nano-clay [5].

Clays can be used for nano-clay production as additive materials. Some are aluminosilicates revealing sheet-like structures. Besides this the layered silicate structures mostly include vermiculite, kaolinite and montmorillonite appertain to the smectite group clays. The thicknesses of layers are generally in the environs of 1 nm. Likewise the aspect ratios are usually in the 100–1500 nm range and hence fairly high. With the bitumen modification, the nano-clay's discs - or layers - need to be modified and separated through the application of surface treatment. Separating the nanoclay layers greatly enhances the its active surface area, which reaches between 700 and 800 m^2/g with this process. With this process a strong and extensive interaction between the asphalt binder and nano-clay develop. Layered silicate can be intercalated or exfoliated in polymer modified bitumen when their scales are nanometric. This polymer chains can intercalate between the clay discs/layers, causing the nano-clay to spread and disperse at a nano-metric level across the polymer matrix. In the conclusions polymer additives enhances mechanical, barrier and thermal characteristics [6].

Nanomaterials such as nanoclay, nano hydrated lime, and nano carbon have significant effects in improving the engineering properties of asphalt binders and mixtures. Many benefits or promising potential of nanoclay materials are concerned with when it was modified with base bitumen for flexible pavement applications. This material has also been used as a secondary modifier to further develop the performance properties of SBS-modified binder [7].

Nano-clay modifications result in considerable improvement in the characteristics of bituminous binders and mixtures; however, further studies need to be conducted before these modifications can be used at larger scales [8]. The main reason for the necessity to conduct further studies before applying these modifications in real settings stems mainly from the limited amount of information on how they actually reduce fatigue and increase rutting resistance in asphalt mixtures. Similar studies have been performed in China on asphalt modified with nano-calcium carbonate (nano-$CaCO_3$) [9,10], which determined that nano-$CaCO_3$ can improve asphalt's temperature resistance (which is normally rather low) and rutting resistance. The asphalt and nano-$CaCO_3$ mixture results in a system of steady and uniform composition that ameliorates asphalt's susceptibility to temperature. Despite such observations, there is still limited understanding of the mechanisms through which such nano-modification change the behavior and properties of asphalt.

The effects of layered silicate in asphalt binder were evaluated and a paucity of studies has been made on nano-composite modified asphalt cement and mixture. For example kaolinite clay has been used for improving storage stability issue in polymer modified asphalt. Although kaolinite clay could increase this issue because of its micrometric scale, no other improvements have been observed for physical and mechanical properties [11,12]. Closite_15A and Nano-fill-15 nano-clay materials were evaluated with asphalt binder and mixtures. Nano-clay additives increased the stiffness, indirect tensile strength, resilient modulus, Marshall Stability and improved the rutting resistance of the modified mixtures. But, fatigue strength decreased at low temperatures [13]. Water sensitivity and tensile strength concepts were studied with nano-clay and carbon microfiber modification. Nano-clay agents improved mechanical strength of the asphalt mixtures. 1.5% nano-clay modification showed higher tensile strength and the moisture susceptibility performance [14].

This study aimed to investigate cracking, stripping and rutting resistance of nano-clay modified asphalt mixtures containing different type nano-clay materials and concentrations (2%-3.5%-5%).

2. Materials and methods

Aggregate combination, bituminous binder and three different nano-clay A-B-C materials were used in experimental stages. Stone mastic asphalt gradation was chosen and 19 mm maximum aggregate size was used. Grain size distribution values were presented in Table 1. Granulometry curve was presented in Fig. 1.

Aggregate material is basalt in view of mineralogy-petrography. Basalt aggregate properties were given in Table 2. Basalt aggregates were evaluated and described based on rock petrography and mineralogical tests. Chemical analyses were performed for the main oxides. The mineralogical composition of the basalt was also determined through chemical analyses, and then confirmed with material selection. Table 3 shows the evaluated basalt aggregate's chemical composition.

AC 50–70 penetration bituminous binder was used. Bitumen properties were illustrated in Table 4 and the cellulose fiber used as a preventive filtration material for SMA design characteristics were given in Table 5.

In addition, nano-clay materials were added to improve the asphalt mixture's mechanical properties. Three different types of nano-clay were employed. Nano-clay materials were produced from bentonite clays supplied from various regions of Turkey. Used bentonite clays for production of nano-clay A, nano-clay B and nano-clay C were obtained respectively from Eskişehir-Kütahya, Eskişehir and Çanakkale regions. Bentonites were dried and grinded nanometric levels. Firstly, bentonites were activated with Na and thus Ca-Bentonites converted to Na-activated bentonites. Na-activated bentonites were purified with centrifuge. It was carried out surface modification with quaternary ammonium salts under the specified reaction conditions. Used organic modifiers were given in Table 6. Also XRF, XRD and SEM methods were performed. Chemical analysis results were given in Table 7 and XRD patterns and SEM images of nano-clays were presented in Figs. 2–7.

Figs. 2 and 4 show that the distance between the layers varies between 34 Å and 37 Å. Nano-clay A showed biggest interlayer distance while nano-clay C has the smallest value. Sieve analysis was done to all nano-clay types and gradation curves showed in Figs. 8–10. Nano-clay A has the largest surface area. Despite having the highest SiO_2 nano-clay C has the smallest surface area (2151 m^2/kg).

When the polymer is unable to penetrate between the silicate sheets, a phase-separated composite is constituted, and the properties stay in the same range for traditional micro-composites. In an intercalated structure, where a single extended polymer chain can penetrate between the silicate layers, a well-ordered multilayer morphology results with alternating polymeric and inorganic layers. Silicate layers are completely and uniformly dispersed in a continuous polymer matrix and so an exfoliated or delaminated structure is obtained. Intercalated and exfoliated structures are mostly desirable for improving the material performance [15].

Table 1
Used SMA gradations and fraction proportions.

Sieve size		Percentage passing	Fraction percentage	Board in Turkey (SMA Type 1-A)	
inch	mm			Lower limit (%)	Upper limit (%)
3/4	19.0	100	Coarse aggregate, 70.9%	100	100
1/2	12.5	92.7		90	100
3/8	9.5	63.5		50	75
No. 4	4.75	29.1	Fine aggregate, 18.7%	25	40
No. 10	2.00	21.6		20	30
No. 40	0.42	14.8		12	22
No. 80	0.177	12.4		9	17
No. 200	0.075	10.4	Filler, 10.4%	8	12