Chapter

The Effects of Using Nano-Silica in Cold-In Place Asphalt with Emulsified Bitumen

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Abstract

Because hot mix asphalt (HMA) is both costly and harmful to the environment, the use of cold in-place recycled (CIR) asphalt is important to highway pavement. But, because CIR pavement properties are not as effective as HMA, addition of additive materials to the mixture is required to improve the pavement characteristics. Effects of using nano-materials on the mechanical properties of CIR asphalt are assessed in this chapter. The results show that the use of nano-materials improves the mechanical properties of CIR.

Keywords: cold in-place asphalt, nano-materials, emulsified asphalt

1. Introduction

The highway network of each country has a vital role in its economic growth and can determine the developed indexes. To address the high cost of implementing new roads, the losses resulting from damaged roads, or other multiple defects of conventional methods for road improvement, specialists have found new ways to improve traditional methods. Limited high-quality aggregate and resources have hindered the development and maintenance of traditional highway roads, making it harder to meet the needs of the society. Recycling is reusing of materials that already have their basic services. With the growing popularity of various recycling methods, asphalt recycling has also had significant growth.

The advantages to the approach presented in this chapter are wide range, all from economic benefits to conservation of natural resources. This method saves time and is in compliance with environmental requirements. It helps retain pavement thickness, rejuvenate and restore existing pavements, remove surface damages, and cure existing cracks. This method is also beneficial, as it does not require the discharge of waste materials by the depot, retains its quality after operation, maintains and develops safe traffic during the implementation of the project, reduces environmental pollution by preventing additional transportation, and applies new materials and sources of aggregates and bitumen.

To reuse the existing pavement, the reclaimed asphalt pavement (RAP) should be converted into usable materials. The well-graded RAP is a mixture of aggregate and good bitumen covered for asphalt production. The in-place recycling asphalt method is further broken down into cold in-place asphalt (CIA) and hot in-place recycling (HIR).

CIA is used in the processes of digging, plowing, scraping, and crushing asphalt layer materials. It is also used in a central asphalt factory to reprocess with bituminous materials at room temperature and without the use of heat. The stratum of recycling is usually coated in proportion to the physical condition with asphalt concrete or surface asphalt [1–4].

Emulsified asphalt pavement has initial and low Marshall stability. The use of additives causes resistance in the produced Marshall asphalt at an early age or later, which can also be effective in improving cold asphalt resistance. In the case of using cement in cold-recycled asphalt to achieve a certain level of density, less energy is required, and the use of emulsified asphalt allows for a more uniform and consistent asphalt. Miró Recasens et al. found that the emulsified asphalt that has cement with Marshall resistance has higher resilience than that without cement. This is mainly due to the fact that higher flexibility, cracking, and the potential of increasing the crack in emulsion asphalt with cement are less [5].

It was observed that in addition to the earlier mentioned benefits of using cement in cold-recycled asphalt, the use of adequate cement in cold asphalt mixture could greatly reduce harmful effects, such as asphalt creeps and cracks. Researchers have found the mathematical relationship between the elasticity model and the amount of used cement in the cold asphalt mixture, along with its preparation process [6].

The effect of modified and unmodified nano-clay in the production of hot asphalt, the used nano-clay from the montmorillonite, has been investigated. In this study, a small percentage of nano-material was observed to have had a great impact on asphalt properties [7–8]. This study also found that a 2% addition of nano-clay to binder asphalt increases the combined shear model to more than 184%. For hot asphalt, modified polymer with nano-clay was used in this study to improve the mechanical properties and thermal resistance of the asphalt. The modification reduces asphalt permeability while improving rupture and compressive strength. Using the modified nano-clay in asphalt causes reduced asphalt viscosity, making it easier to implement the asphalt. The use of modified nano-clay also increases the ability of asphalt recycling. Microscopic photos illustrate how the use of modified nano-clay can lead to better and more complete molecular bonds. The use of nanoparticles increases durability of the produced asphalt. For example, with the use of 2–4% of nanoparticles in asphalt, the crack depth is half reduced [11].

In their article "The use of nano-silica in concrete mixes," Garcia and Brawerz of Eindhoven University in the Netherlands indicated that the use of silica in place of cement reduces the cement-produced CO_2 level and increases the strength and durability of the concrete, due mainly to the use of nano-silica in the concrete mix [9, 10].

The trial, however, did not focus on the effects of nanoparticles on cold-recycled asphalt. This chapter details the financial, environmental, and other factors (not including hot and emulsified asphalt) affecting the performance and development of civil engineering projects that use cold-recycled asphalt. This chapter investigates the effect of nano-materials on the recycling cold mixture.

2. Methodology

The modified Marshall method, which is based on ASTM-D1559 or AASHTO T245 and is different from hot mixed asphalt (HMA), is used for CIA with emulsified asphalt. The emulsified asphalt in this design is used in mixtures that are prepared in accordance with ASTM-D5505; RAP materials, and if necessary, new aggregate materials are used as well. The amount of used emulsion in the Marshall mix method ranges usually from 1 to 2%, and young emulsions vary from 5.0 to 1.25% compared to the weight of the asphalt mixes. The more the mixtures, the higher their percent of broken aggregates, and a lesser amount of available bitumen is used in RAP. Lower percentages are used in mixes with high levels of fine and rounded corners. When the new aggregate is added to RAP, the young emulsion is not used, while the percentage of emulsified asphalt should be increased. In order to estimate the percentage of the primary emulsified asphalt for this design, a method has been used in which a given amount of emulsified asphalt was chosen as the base percentage; and the amount of bitumen and the degree of recovered bitumen penetration from hard bitumen, in terms of RAP grading, are reformed.

Nanoparticles are defined as particles smaller than 0.09 mm. Some methods of producing nanoparticles include grinding through washing or replacing. These methods often require advanced nuclear devices.

Properties of nano-material are always defined in nano-material mass, namely, the properties of the particles themselves are not apart from the properties of the particle bulk, and the behavior of the particle bulk represents the mechanical and chemical properties of nanoparticles.

Since each nanoparticle has a unique size, shape, and surface, their behavior and reaction should be examined in combination with other available substances [11].

The following formula is used to estimate the amount of needed emulsified asphalt for the recycled mixture:

$$E = 1.2 + A_G + A_{AC} + A_{PV} \tag{1}$$

where, E = the percentage of required bitumen, 1.2 = the fixed percentage of bitumen, A_G = the correction factor for the size in terms of percent, A_{AC} = the correction factor for the percentage of existing bitumen in recycled mixture in terms of percent, A_{PV} = the correction factor for penetration grade.

In cases where E comes to have different results for a recycled material sample, the bitumen percentage is shown to be less (Publication 339). The water amount can be obtained from the following equation:

The water mixture should be added = 3-(the moisture percent of aggregate mixture + the percentage of the water in bitumen mixture). Nano-material has been added to the water and mixed; then the blended materials have been added to the emulsified asphalt.

Emulsified asphalt, which has been heated to 60°C, is added to the mixture, in accordance with the project's needs for each specific bitumen percentage and 0.5 difference. The resulting mixture is stirred until the emulsified asphalt or rejuvenating emulsion is evenly distributed in the material.

In order to detect changes in the percentage of additives to the asphalt, three compacted Marshall samples (by the standards of ASTM-D1559 and AASHTO-T254); one crushed sample, for determining the real specific weight (by the standards of ASTM-D2726 and AASHTO-T166); and one non-crushed sample, for determining the maximum real density and the percentage of the sample's free space (by the standards ASTM-D2041 and AASHTO-T209), were created.

The initial speculation for the addition of the emulsion to the mix is as follows:

Percentage of bitumen = 1.2% + 0% + 0% + 2% + 0% =

According to the above speculation, the three Marshall sample series with values of 1.5, 2, and 2.5% of emulsified asphalt were made without the addition of any additives. Since adding 3% of water to the produced mixture can help make a better blend of the mixture, the samples in this project were combined with 3% of water to the cold asphalt mixture and then tested.

To further examine the compatibility of cement and nano-silica, nano-alumina, nano-clay, and nano-lime with cationic emulsion and nano-silica and cement with each other (both have a negative surface charge), the combinations were used and tested for the first time in recycled mixture of cold asphalt. Three sets of samples with values of 0.5, 1, and 1.5% of nano-silica were obtained to determine the optimal amount of nano-silica when combined with optimal cement. **Figures 1**–**3** show the effects of nanoparticles in fatigue property of CIR.

The different parameters and additives were considered for each case as the obtained results were compared with the results of previous studies and the conformance or nonconformance results.

All nano-silica, nano-alumina, nano-clay, and nano-lime and cement were combined and used in this study, first because of their compatibility in cationic emulsified asphalt and second because of the effects cement has on increasing the Marshall stability of CIP.

The combined use of nanoparticle and cement are effective in increasing the ultimate strength and in protecting the environment due to the effects combined nanoparticle and cement have on increasing the Marshall stability of the produced samples and reducing the level of the produced CO_2.

The higher the real specific weight, the more rigid the produced pavement is. As resistance against pavement fatigue is improved, the resistance and the reliability of the pavement are increased as well. The actual real specific weights of the produced samples, compared to samples produced without additives, are increased by 8 and 10% with the addition of cement and nano-silica, respectively.

The addition of nano-silica and cement at the same time increased the strength and resistance to pavement fatigue and reduced parts of the asphalt flow and the comfort while the car is moving on the pavement. The addition of any additives to the cold asphalt mixture reduces the sample's free space percentage and results in a more compacted and condensed body. When nano-silica and cement are combined, the reduction in free space is impressive.

The combination increases the sample's air void by 20% without the additive. The additives can help limit the influence of surface water from the pavement to the body with regard to the provision of proper drainage in the lower layers of the pavement.

On the other hand, the presence of other additional fillers (additives) fills the aggregate pores with more fine materials, making the mixture more efficient. Finally, in addition to the positive impacts of the earlier stated factors, the effects were observed in the increased Marshall stability and resistance against fatigue in the cold asphalt mixture.

Other parameters of the cold asphalt mixture and the potential to replace this type of asphalt with hot mixed asphalt were considered by taking advantage of CIP instead of HMA to examine the measure of flow and the existing limitations.

The flow of samples made with nano-silica and cement additives was acceptable. Due to the maximum real density of the samples, it can be stated that with the addition of various additives, the maximum theoretical density of asphalt is higher.

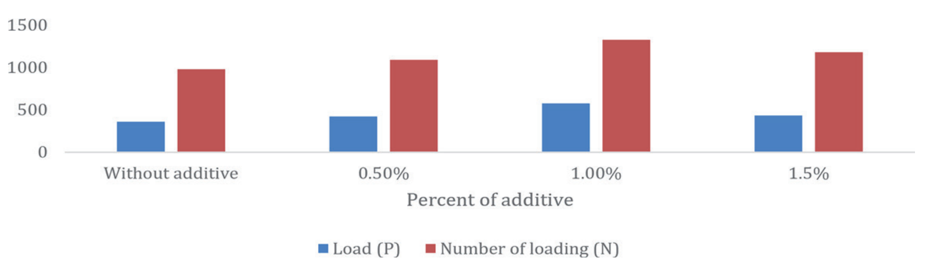

Figure 1.
Comparison of load and number of repetitions in stress ratio 0.2.

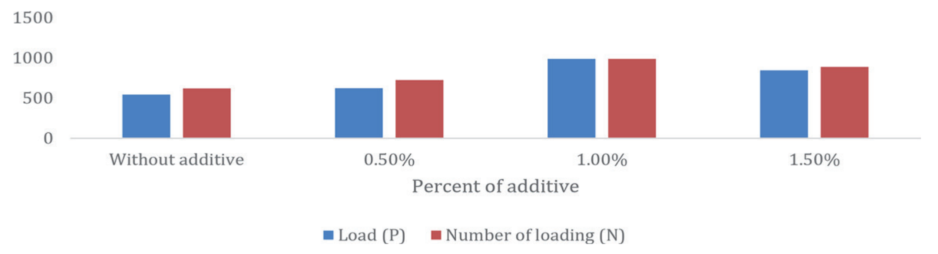

Figure 2.
Comparison of load and number of repetitions in stress ratio.

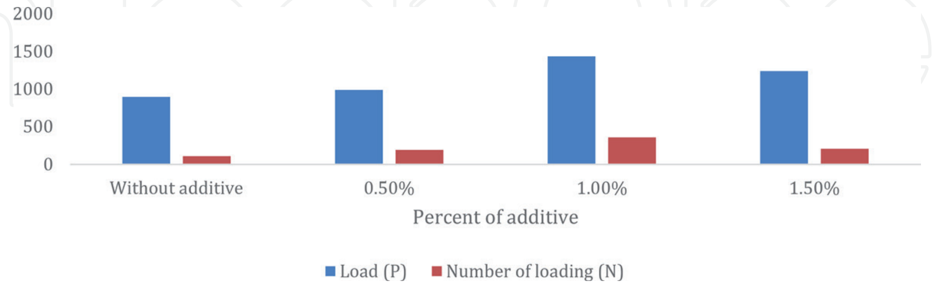

Figure 3.
Comparison of load and number of repetitions in stress ratio 0.5.

Active fillers, which have higher adhesion properties, cause the specific weight gain because of the physical and chemical bonds between aggregates. The addition of nano-silica and cement has improved the maximum theoretical density of the asphalt mixture by 3 and 4% compared to the mixture without additives. The increase in maximum theoretical density of additives with more adhesion strength is more; these findings are consistent with the assumptions made at the initial stages of this research.

3. Conclusion

Cold emulsified asphalt has low initial value and Marshall resistance. Additives can, therefore, be used to improve the mechanical properties. According to the assumptions made for this research, the use of nanoparticle rather than an active filler in a recycled cold asphalt mixture improves the Marshall resistance of samples and reduces the free space percentage of the mixture. It is anticipated that the use of nanoparticles in place of the active filler improves efficiency of the mixture and homogenizes the asphalt mixture. This study attempted to find a logical relationship between the types of additives in recycled cold asphalt and the extent of effective parameter changes made in asphalt while also commenting about the positive and negative effects of each additive on the different parameters of recycled cold asphalt.

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