Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(10) (2022) 915-918
DOI: 10.22060/ceej.2020.18119.6773

Evaluating the Rheological and Mechanical Properties of Asphalt Mixtures Modified with Nano Copper Oxide

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ABSTRACT: The performance of the asphalt mixture against damage is related to two main factors: external factors and internal factors. External factors are characteristics that are related to environmental factors such as weather conditions, drainage, and traffic. Internal factors are characteristics that are related to the asphalt mixing design, such as the properties and amount of aggregate, the properties and amount of bitumen, the properties of the filler, and the asphalt mixing mix design. Although bitumen has a small volume of asphalt mixture, its role in different temperatures on different failures of asphalt mixture is very important. The growth of the transportation network has led to a special need for the life cycle cost analysis and increase the lifespan of asphalt mixtures. There are several ways to improve the performance of asphalt mixtures, one of which is bitumen modification using modifiers. In recent years, with the invention and expansion of the production of nanomaterials, special attention has been paid to the use of nanomaterials to improve the rheological properties of bitumen. Accordingly, this study evaluates the effect of copper nano oxide on the rheological behavior of bitumen and the mechanical properties of the asphalt mixture. Therefore, the dynamic shear rheometer is used to determine the specifications of bitumens at medium and high temperatures, as well as fatigue and dynamic creep tests to investigate the performance of asphalt mixtures against fatigue cracking and rutting. The results of bitumen rheological experiments show that the use of copper nano oxide at 1 and 2 percent by weight of bitumen improves the rutting parameter in unaged and short-term aged bitumen from 49-343 and 57-257 percent, respectively, and also improves the fatigue parameter in long-term aged bitumen from 11-40 percent. The results of fatigue tests show that the fatigue life of samples containing 1 and 2 percent of this additive at 5 and 20 °C will improve by 9-16 percent and 6-31 percent, respectively. Also, the results of the rutting potential show that the use of 1 and 2 percent of nano oxide has reduced the permanent deformation change of 13-35 and 18-18 percent, respectively.

Review History:
Received: Mar. 15, 2020
Revised: May, 06, 2020
Accepted:May, 08, 2020
Available Online: May, 27, 2020

Keywords:
Hot mix asphalt
Copper nano oxide
Rutting
Fatigue cracking
Dynamic shear rheometer

1. INTRODUCTION

Due to the passage of heavy vehicles as well as the overloads carried by these vehicles, repetition of various loads is introduced. These loads often cause extensive stresses (such as fatigue) on pavement, which can lead to a variety of pavement failures. The presence of cold winters or very hot summers, changes in temperature, heavy rainfall and the continuation of freezing and thawing periods cause major stresses in pavement, which is another factor for common pavement failures [1].

There are several ways to improve the rheological properties of bitumen at different temperatures, as well as the performance of the asphalt mixture against various failures.

The use of high-quality materials, bitumen modification, granulation modification, the use of suitable fillers and the use of various additives over the past years have been the focus of various researchers. The use of additives has been considered in the past decades due to the type of asphalt mixture, weather conditions and mixing design variables [2]. The growth of nanotechnology and the characteristics that have led to the use of these materials have led to an increase in attention to this family of materials over the past two decades. Different types of nanomaterials have been considered due to their long-term durability and multi-purpose use in road construction technology and modification of asphalt mix properties [3].

2. METHODOLOGY

In this study, the effect of nano CuO on bitumen rheological parameters, including mixed modulus (G*) and phase angle (δ) at medium and high temperatures, was measured using dynamic shear rheometer (DSR) test. Then, the parameters related to bitumen performance against fatigue cracking (G*sin δ) and groove (G*/sin δ) are calculated.

Also, the effect of nano CuO on the performance of asphalt mixture at medium and high temperatures has been investigated. For this purpose, fatigue test by indirect tensile fatigue test to determine the fatigue life at 5 and °C under 5

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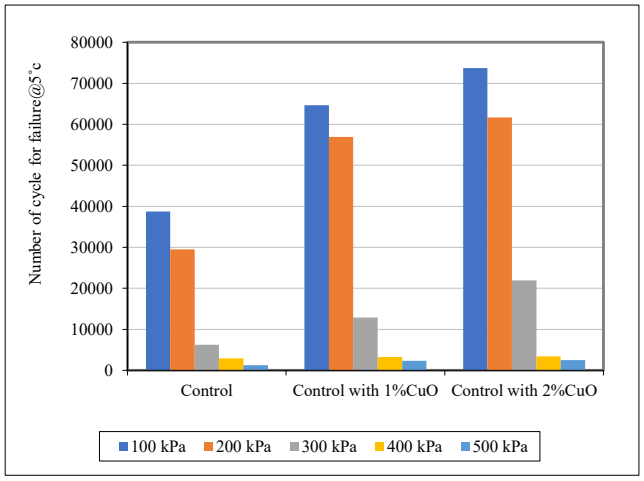

Fig. 1. Number of fatigue life cycles at 5 °C

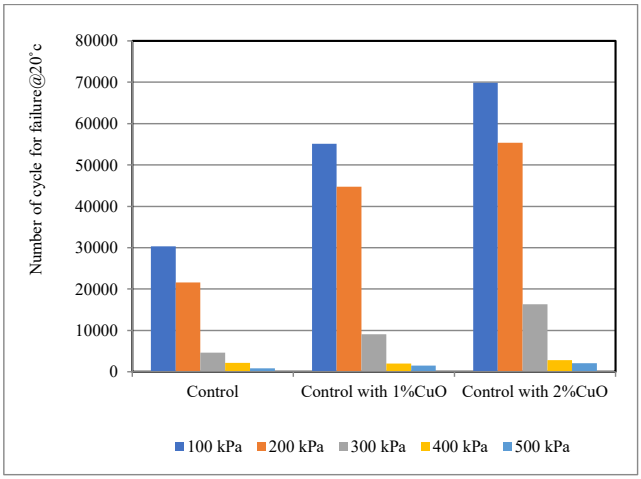

Fig. 2. Number of fatigue life cycles at 20 °C

different stress levels and rutting test using repeated loading at 40 and 60 °C under 2 different stress levels.

In this study, nano CuO was used in 2% of bitumen mass. The construction and compaction of asphalt mix samples were performed using Marshall mixer and compactor, respectively. The mixing temperature of bitumen and aggregates for base bitumen, modified with 1 and 2% nano CuO, is 152, 158 and 163 °C, respectively. It should be noted that the stone materials were placed at a temperature of 160 °C for at least 4 hours before mixing and then reached the bitumen mixing temperature.

3. RESULTS AND DISCUSSION

Results of rheological bitumen modified bitumen tests have a higher rutting factor than basal bitumen at all temperatures. Further values of the rutting factor indicate that the modified bitumens are less sensitive to rutting or permanent deformation. This suggests that the use of nano CuO could significantly improve the performance of modified bitumens in hot weather conditions.

Modified bitumen with nano CuO in both percents (1 and 2% by weight of bitumen) has lower values of fatigue factor than base bitumen. Asphalt mixtures containing modified bitumen with nano CuO can be expected to have a longer fatigue life than control mixtures.

Due to the fact that fatigue cracking actually occurs when the bitumen is aged due to sunlight and hot air movement, the DSR test to determine the potential for fatigue cracking is also performed on long-term aged bitumens. The use of nanomaterials reduces the aging rate of bitumen because they act as a barrier to the evaporation of light particles of bitumen as well as changes in the molecular structure of bitumen. This reduces the cracking potential of the modified bitumens compared to the control bitumens. Also, the continuous structure of nanoparticles in the bitumen space reduces the time interval between stress and strain, which increases the elastic properties of the modified bitumen, which reduces the fatigue factor and improves the performance of the modified bitumen against this type of failure.

According to Fig. 1 and 2, it is observed that asphalt specimens modified with nano CuO significantly exhibit better fatigue performance than simple asphalt specimens. The use of nano CuO increases the hardness of the asphalt mixture. Increasing the hardness has two different effects on fatigue life. The first effect is that it reduces the amount of tensile strain under the top layer, which increases the fatigue life. The second effect is that increasing the hardness reduces the flexibility of the asphalt mixture and reduces its fatigue life.

The use of nano CuO additives in Figures 3 and 4 has significantly reduced the amount of permanent deformation at the end of the 2000 cycle compared to the control samples. Copper has an amorphous structure. In addition to creating non-polar bonds with bitumen, which strengthens its adhesion to aggregates, these structures can increase the hardness of bitumen at high temperatures, which reduces its resistance to grouting.

Figures 5 and 6 show the results of dynamic creep tests to

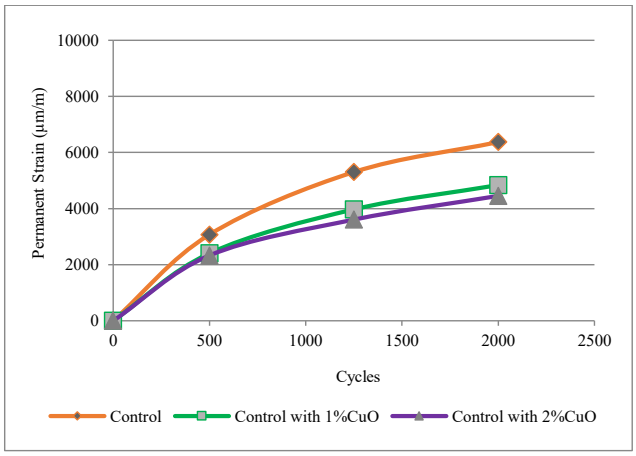

Fig. 3. Permanent deformation at 40 °C and 200 kPa

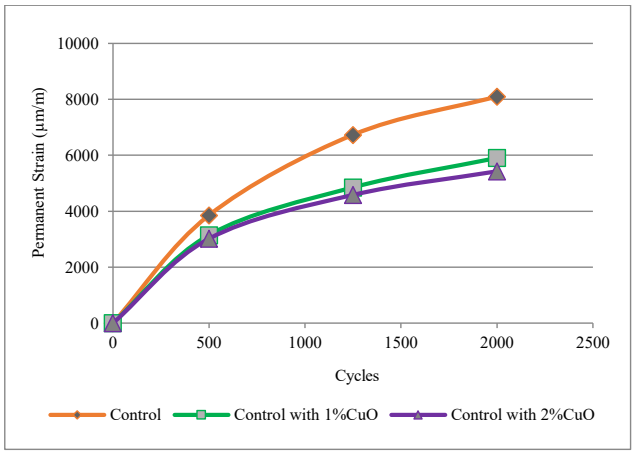

Fig. 4. Permanent deformation at 40 °C and 400 kPa

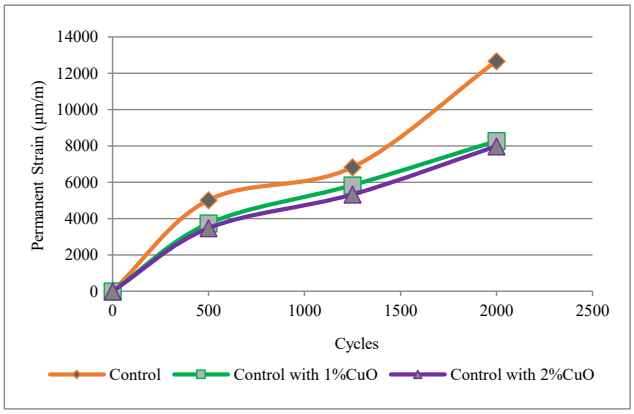

Fig. 6. Permanent deformation at 60 °C and 400 kPa

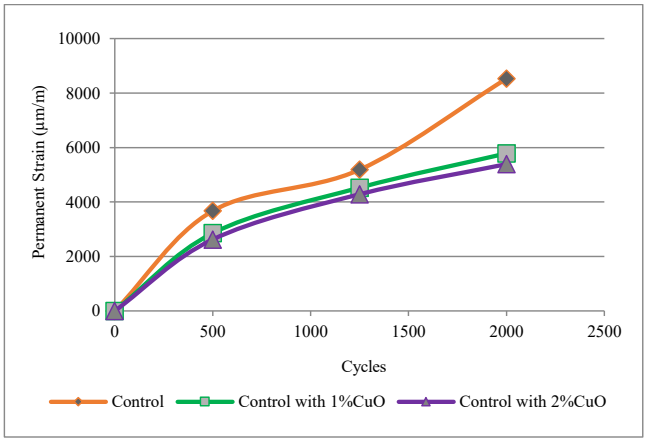

Fig. 5. Permanent deformation at 60 °C and 200 kPa

determine the rutting potential of asphalt mixtures at 60 °C under two stress levels of 200 and 400 kPa. The results show that the use of 1 and 2% of nano CuO significantly reduced the amount of permanent deformation of the modified samples.

4.CONCLUSIONS

• The use of nano CuO increases the grouting factor in modified bitumens, which can reduce the grouting potential of asphalt mixtures containing these bitumens at high temperatures.

• Nano CuO additives improve the fatigue properties of modified bitumens, thus delaying premature fatigue cracks in mixtures containing modified bitumens.

• The use of nano CuO has significantly reduced the rate of permanent deformation of modified specimens with this material compared to control specimens.

• The use of nano CuO has increased the fatigue life of asphalt mixtures to two temperatures and five stress levels used in this study. This allows asphalt mixtures to perform better at medium temperatures.

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HOW TO CITE THIS ARTICLE

Gh. H. Hamedi, Evaluating the Rheological and Mechanical Properties of Asphalt Mixtures Modified with Nano Copper Oxide, Amirkabir J. Civil Eng., 53(10) (2022) 915-918.

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