Experimental Investigation of Nano Zinc Oxide Effect on Creep Compliance of Hot Mix Asphalt

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Abstract

In recent years, many researches were down to improve service life of asphalt pavement quality against vehicles dynamic loads. For this purpose, researchers investigated different ways such as changing the aggregate gradation and using of additive material to modify bitumen and asphalt mixture. One of this ways is using of additive materials to improvement of asphalt properties against dynamic loads. Due to unique characteristics of nano materials, using of them in asphalt mixtures has been interested. Therefore, in this study the effect of nano zinc oxide (ZnO) in improvement of mechanical properties of hot mix asphalt (HMA) has been investigated. To achieve this goal, mixtures with different content of bitumen and nano zinc oxide were made and the effect of these parameters was investigated on the modified mixture in compare with conventional asphalt mixture. The results showed that adding of nano zinc oxide to HMA had a great effect in the improvement of permanent deformation of HMA.

Key words: HMA, Nano Materials, Creep Compliance, Permanent Deformation

1. Introduction

Damages that occur before the useful life of pavement that mainly are rutting, permanent deformation and fatigue cracking. Since the recovery and reconstruction of defects will be costly, therefore, the prevention of such cases would be more economical. To avoid failure, one of the methods is to modify the properties of bitumen. Researchers have used different methods including the use of various types of polymers and fibers [Kok et al., 2007]. To improve the performance of bitumen and asphalt concrete mixtures, the addition of modifiers such as nano materials has become popular in recent years. Nano composites are one of the most popular materials discovered recently to improve properties of asphalt and asphalt mixture [Pinnavaia et al., 2000]. Nanotechnology is a general term that refers to all technologies in the field of nanoscale. Typically, the Purpose of nanoscale is from about 1nm to 100nm. This technology has attracted the attention of many researchers. Ghaffarpour et al. carried out comparative rheological tests on binders and mechanical tests on asphalt mixtures containing unmodified and nanoclay modified bitumen. Results showed that nanoclay can improve properties such as stability, resilient modulus, and indirect tensile strength, but it do not seem to have a beneficial effect on fatigue behavior in low temperature [Ghaffarpour et al., 2010]. Golestani et al. evaluated Performance of modified asphalts binder by nano composite. The physical, mechanical and rheological properties of original bitumen, and modified bitumen by nano composite have been studied and compared. The results showed that nano composite can improve the physical properties, rheological behaviors and the stability of the bitumen [Golestani et al., 2012]. Martin et al. investigated nanotechnology effects on the adhesion of asphalt mixtures. Two different types of nanoclay were used to modify bitumen. In the first case, Viscosity of modified bitumen in comparison to original bitumen (70-100) did not change after the addition of 6% (by weight) of nano-clay, although improved its short-term and long-term hardening. In the second case, Nanoclay increased viscosity of bitumen. Therefore, this type of modifier is appropriate to use in asphalt mixtures to prevent water penetration [Martin et al., 2008]. Ghasemi et al. evaluated the potential benefits of nano-SiO_2 powder and SBS for the asphalt mixtures used on pavements. Five bitumen formulations were prepared using various percentages of SBS and nano-SiO_2 powder. Then, marshall samples were prepared by the modified and unmodified bitumens. The results of this investigation indicated that the asphalt mixture modified by 5% SBS plus 2% nano SiO_2 powder could give the best results in the tests carried out in the current study. So that this modification can increases physical and mechanical properties of bitumen and mixtures[Ghasemi et al., 2012]. Khodadadi et al. investigated Nanoclay additive effect on long-term performance of asphalt pavement. Indirect tensile test were conducted on cylindrical specimens made of standard and modified bitumen at the stress levels of 200, 300, 400 and 500 kPa. The results showed that the addition of 2% nanoclay increases the fatigue life of the asphalt pavement [Khodadadi et al., 2007]. Many researches are down about bitumens modified with Nano materials, but it is the first time that modification with nano Zinc oxide (ZnO). Zinc oxide nanoparticles have bigger aspect ratio and a large surface area in comparison with normal zinc oxide, and their particles are not uniform in size and arrangement. It is much more active in terms of chemical. By adding these materials to bitumen, because the bonds that are formed between the material and the bitumen, Properties of bitumen, including the softening point, penetration grade, and ductility are improved. It is expected that modification of bitumens with Nano materials improve the mechanical properties of asphalt mixtures including increase of stiffness modulus, increase of strength against stripping, increase of strength against moisture damage, Prevention of cracks and increase of resistance against creep compliance. The aim of this study is to evaluate the influence of nano ZnO on the engineering properties of bitumen and asphalt concrete mixtures. For this purpose, they were performed penetration grade, softening point, and ductility tests on modified bitumen by four different content of nano ZnO and repeated load axial (RLA) test on asphalt concrete mixtures by three different content of nano ZnO.

2. Experimental

2.1. Materials

The aggregates used in this study were graded using the continuous type IV scale of the AASHTO standard, which is presented in Table 1 [AASHTO, 1993]. Bitumen was a 60/70 penetration grade and its properties are shown in Table 2. Also, Properties of nano ZnO are shown in Table 3.

Sieve(mm)	19	12.5	4.75	2.36	0.3	0.075
Lower–upper limits	100	90 – 100	44-74	28-58	5-21	2-10
Passing (%)	100	95	59	43	13	6

Table 1. Gradation of aggregates used in the present study

Test	Standard	Result	Specification limit
Penetration (100 g, 5 s, 25 ºC), 0.1 mm	ASTM D5-73	68	60-70
Ductility (25 ºC, 5 cm/min), cm	ASTM D113-79	112	Min 100
Solubility in trichloroethylene, %	ASTM D2042-76	99.5	Min 99
Softening point, ºC	ASTM D36-76	51	49-56
Flash point, ºC	ASTM D92-78	250	Min 232
Loss of heating, %	ASTM D1754-78	0.2	Max 0.8

Table 2. Properties of bitumen used in this study

Specification	Result
Molecular formula	ZnO
Molecular Weight (g/mol)	81.4
Color	white
Odor	odorless
Particle size (nm)	50
Specific Gravity(gr/cm^3)	5.6
Flash point (C°)	1436
Melting Point (°C)	1975
Boiling Point (°C)	2360
Weight loss after burning (%)	Less than 0.6%
Solubility In Water (30 °C)	0.00016 g/100ml

Table 3. Properties of nano zinc oxide used in this study

2.2. Experimental Setup and Procedure

The tests generally used to assess the resistance of asphalt concrete mixtures to permanent deformation are the Marshall test, the static creep test, the dynamic creep test, repeated axial load test (RLA), and the wheel-tracking test [Niazi et al., 2009]. In this study, the resistance to permanent deformation of modified asphalt concrete mixtures by different nano ZnO was evaluated by using RLA test.

For this study, cylindrical samples were made with a diameter of 101 mm and the height is 70 mm. Specimen preparation and compaction were conducted in accordance with ASTM D1559 [ASTM, 2002]. The RLA test was used to evaluate the effects of nano zinc oxide on the creep behavior of asphalt mixtures. The nano ZnO content selected were 2%, 5%, 8%, and 11% by weight of bitumen.

2.3. Laboratory Tests

2.3.1. Empirical Rheological Tests on bitumen

To determine the optimum content of Nano ZnO, empirical rheological tests carried out on conventional and modified bitumen with different nano ZnO content were penetration grade, softening point, and ductility tests. The modification of bitumen with nano ZnO was performed at nano scale level by thermodynamic driving force. The empirical tests were performed according to the standard test procedures. The penetration test is an empirical test which measures the consistency (hardness) of asphalt at a specified test condition according to ASTM-D5 standard. For determination the softening point of bitumen in the range from 30 to 157°C, the ASTM-D36 is used. Also ductility of bitumen is determined according ASTM-D113 standard. This test method provides one measure of tensile properties of bituminous materials and may be used to measure ductility for specification requirements.

2.3.2. Repeated Load Axial Test (RLA)

To determine the optimum content of Nano ZnO, RLA test has been used for a long time to determine creep behavior of the asphalt, which is because of its simplicity and logic relation with permanent deformation of asphalt mixture. The most important outcome of RLA test is accumulative strain curve facing number of loading cycles which depends on compound rutting strength. Fig. 1 depicts a form of this curve. As shown in Fig.1, the curve was made of three major parts: primary stage with relatively large deformation during a short number of cycles; secondary stage which the rate of accumulation of permanent deformation remains constant; and tertiary stage, the final stage that the rate of deformation accelerates until complete failure takes place. This stage is usually associated with the formation of cracks [Ghaffarpour et al., 2010].

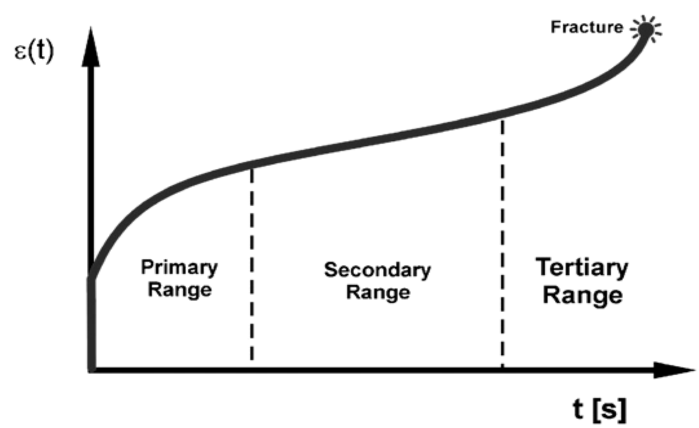

Fig 1: A typical creep curve

The creep compliance was determined by applying a dynamic compressive load (repeated load axial) of fixed magnitude of 200, 300 or 400 KPa for 1 h at different temperature 40, 45, 50, 55, and 60°C along the diametric axis of a cylindrical specimen. The resulting vertical deformation was measured by two LVDTs. In each test, the sides of the specimen were capped and the sample was placed in the loading machine under the conditioning stress of 10 KPa for 600 s. Next, the conditioning stress was removed and the stress of 200, 300 or 400

KPa was applied for 2000 cycles, which included a 1-s loading period and a 1-s resting period [Arabani et al. 2012].

3. Results and Discussions

3.1. Empirical Rheological Tests on bitumen

Figures 2-4 are presented the results of penetration grade, softening point, and ductility tests.

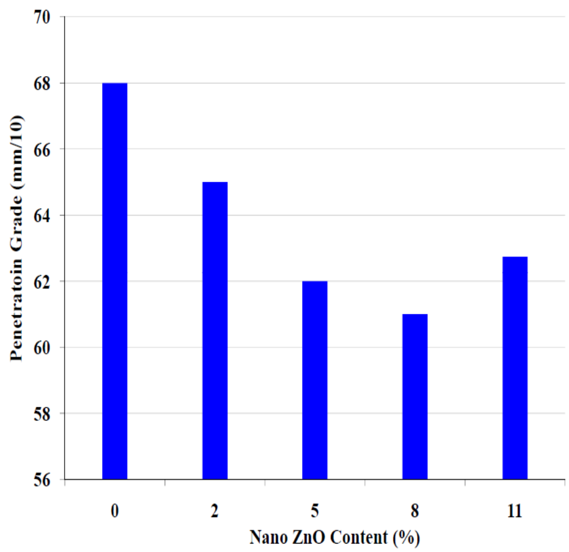

Fig 2: Penetration grade test results on unmodified and modified bitumen.

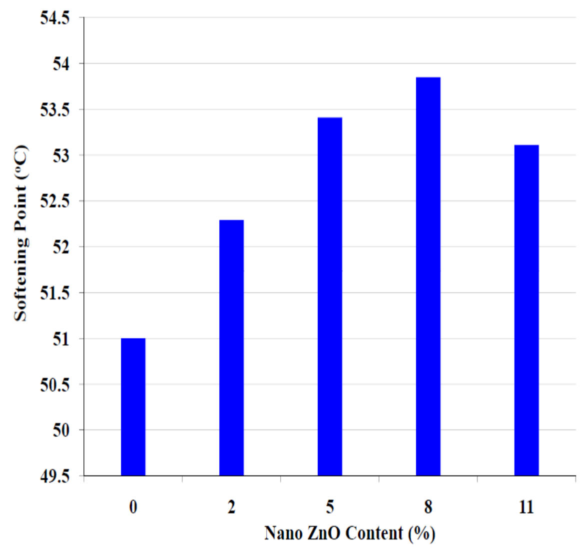

Fig 3: Softening point test results on unmodified and modified bitumen.

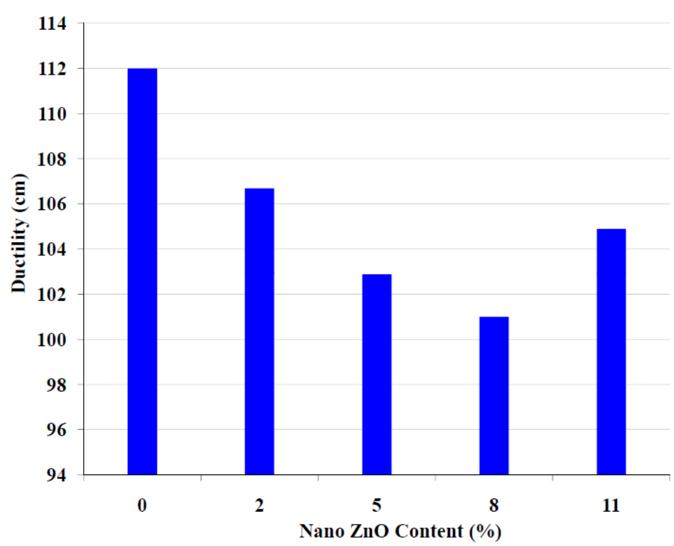

Fig 4: Ductility test results on unmodified and modified bitumen.

It can be seen from figures 2-4 that adding percentages of nano ZnO has positive effect on the rheological properties of bitumen. The viscosity of bitumen is increased by adding the nano ZnO. Subsequently, penetration grade of modified bitumen is decreased. Moreover, by decreasing temperature sensitivity of modified bitumen due to adding nano ZnO, the softening point of bitumen is improved. It is illustrated in figure 4 that ductility is significantly decreased by improvement of modified bitumen stiffness in comparison to conventional bitumen. The results obtained by the penetration grade, softening point, and ductility tests for bitumen showed that 8% nano ZnO as modifier of bitumen is an optimal content. In 11% nano ZnO, penetration and ductility was increased and softening point was decreased. As a result, to evaluate the effect of nano ZnO on the creep compliance of asphalt mixtures, the samples were made with modified bitumen by percentages of 2%, 5% and 8% nano ZnO.

3.2. Repeated Load Axial Test (RLA)

The values of final strain versus Nano ZnO content in asphalt specimens at different stresses and temperatures are shown in Fig. 5-9.

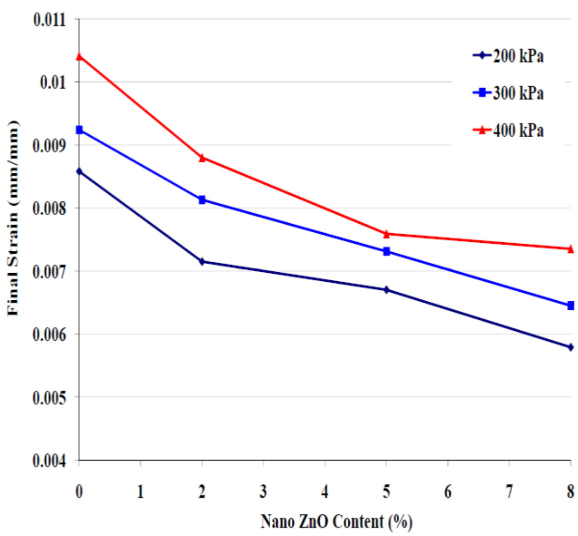

Fig 5: Variation of final strain versus Nano ZnO content in asphalt specimens at 40ºC

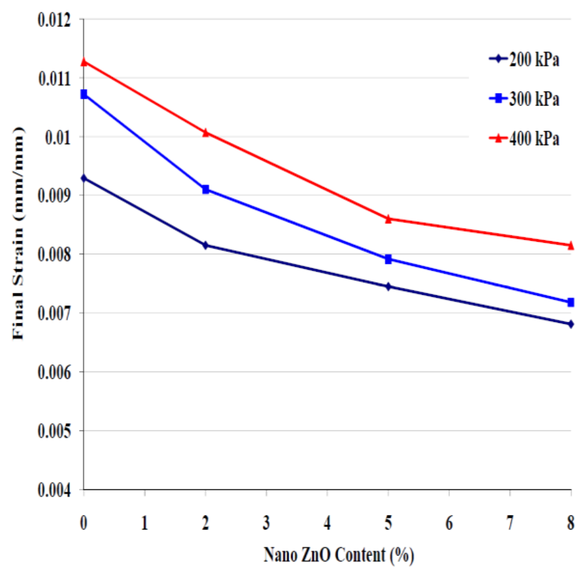

Fig 6: Variation of final strain versus Nano ZnO content in asphalt specimens at 45ºC.

The results of the RLA tests that presented in figures 5-9 show that the samples without nano ZnO have more permanent deformation than the samples containing nano ZnO as modifier of bitumen.

The amount of final strain at a special temperature for samples with different containing nano ZnO is less than conventional samples. From Figures 5-9, it can be concluded that greater adhesion between aggregate and modified bitumen in asphalt mixture in compare with conventional asphalt mixtures is the main reason of decreasing mixture final strain. It can be seen from figures, increment of temperature cause significant increase in the amount of final strain of asphaltic samples. For a special mixture like modified sample with 5% nano ZnO, the amount of final strain at 60 °C is about 1.28 times of final strain at 40 °C. Also, another remarkable point was that the process of decreasing final strain due to nano content increase would be less by increasing temperature. Because of the high sensitivity of the bitumen to the variations of temperature, the final strain and permanent deformation of the conventional and modified mixtures decreased at higher temperatures. This phenomenon could be explained by the viscosity and stiffness modulus of the bitumen, which decreased at higher temperatures.

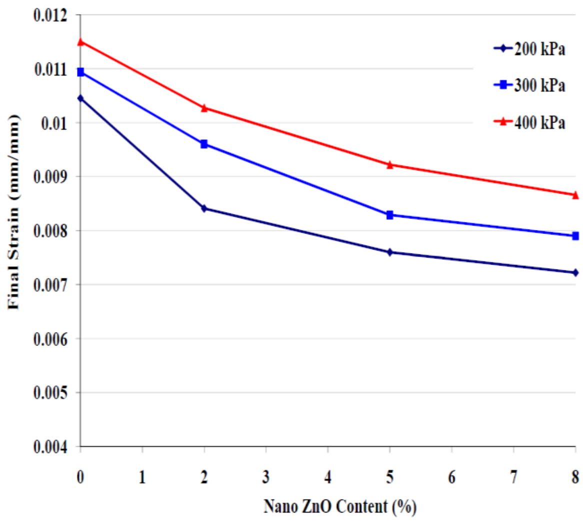

Fig 7: Variation of final strain versus Nano ZnO content in asphalt specimens at 50ºC.

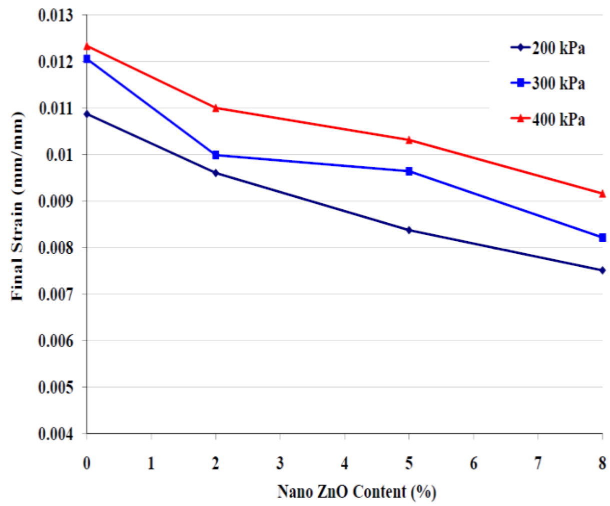

Fig 8: Variation of final strain versus Nano ZnO content in asphalt specimens at 55ºC.

The results obtained by this research show that the best replacement for reducing final strain and permanent deformation of samples is the replacement of 8% bitumen with nano ZnO. In results, replacement of 8% bitumen with nano ZnO can improve creep behavior of asphalt concrete mixtures.

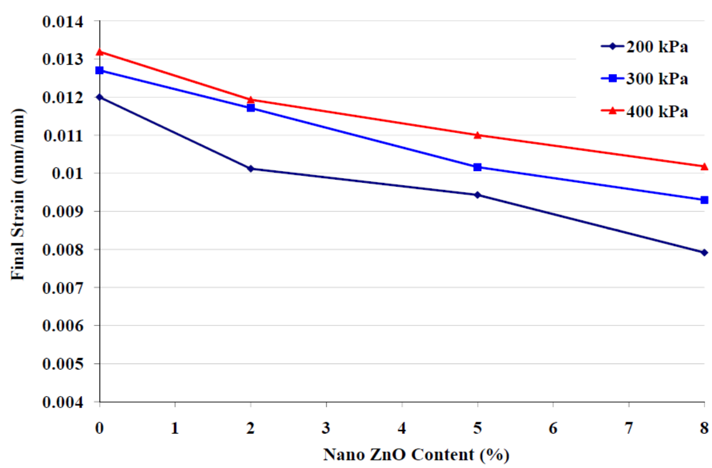

Fig 9: Variation of final strain versus Nano ZnO content in asphalt specimens at 60ºC.

4. Conclusions

The objective of this study is to evaluate the effects of nano ZnO as modifier of bitumen in creep compliance of hot mix asphalt. Repeated load axial test was used to evaluate the creep characteristics of hot mix asphalt by varying contents of nano ZnO. Based on the laboratory test results, the following conclusions were obtained:

- The results obtained by the penetration grade, softening point, and ductility tests for bitumen show that 8% nano ZnO as modifier of bitumen is an optimal content.
- The results obtained by the repeated load axial tests for samples show that 8% nano ZnO as modifier of bitumen is an optimal content in asphalt mixtures.
- Using nano ZnO as modifier of bitumen in hot mix asphalt increases the efficiency of asphalt mixes. It is found that replacing 8% of the bitumen by nano ZnO improves the creep compliance behavior of the asphalt mixtures.
- By increasing the temperature, final strain of all specimens decreases. This behavior results from high sensitivity of bitumen in asphalt mixtures to temperature.

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