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# Evaluation the effect of nano-$TiO_2$ on the rutting and fatigue behavior of asphalt mixtures

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## HIGHLIGHTS

- Using of modified bitumen with nano-$TiO_2$ in HMA increases the efficiency of asphalt mixture.
- Replacing 5% of the bitumen by nano-$TiO_2$ improves the creep behavior of the asphalt mixtures.
- By increasing the temperature, final strain of all modified specimens increases.
- Addition of nano-$TiO_2$ can improve the creep behavior of asphalt mixture even at high temperature.
- Nano-$TiO_2$ prevents tensile cracks from being easily generated by horizontal tensile stresses.

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## ABSTRACT

Many researches were carried out to improve service life of asphalt pavement against vehicles dynamic loads. One method is to use of additive materials. Due to unique characteristics of nano-materials, using of them in asphalt mixtures has been interested. Therefore, in this study the effect of nano-Titanium dioxide ($TiO_2$) has been investigated to improve HMA properties. To achieve this goal, mixtures with different content of bitumen and nano-Titanium dioxide were made and the effects of these parameters were investigated on the modified mixtures in comparison to conventional asphalt mixtures. With the experimental results and the numerical analysis, experimental models were proposed for prediction of the creep behavior and fatigue performance of both conventional and modified asphalt mixtures by nano-$TiO_2$ for different conditions depending on temperature and stress. The results showed that adding of nano-$TiO_2$ leaded great improvements on permanent deformation and fatigue life of HMA.



## 1. Introduction

Damages that occur before the useful life of pavement 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 [1]. 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 to improve properties of bitumen and asphalt mixture [2]. Nanotechnology is the creation of new materials, devices, and systems at the molecular level as phenomena associated with atomic and molecular interactions strongly influence macroscopic material properties [3]. This technology has attracted the attention of many researchers. Many researches are carried out on modified bitumen with nano-materials. Titanium dioxide nano-particles have large surface area in comparison with normal Titanium dioxide, and are not uniform in size and arrangement [2]. By adding these materials to bitumen, because the bonds that are formed between material particles and the bitumen, Properties of bitumen, including the softening point, penetration, and ductility are improved. It is expected that modification of bitumen 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 [2].

## 2. Literature review

Many researches were carried out to improve service life of asphalt pavement against vehicles dynamic loads by using of nano-materials. Tanzadeh et al. evaluated the effect of nano-$TiO_2$ on rutting performance of asphalt pavements. The purpose of this study was laboratory research on the effect of nano-$TiO_2$ in

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improving Bitumen property and rutting resistance in Asphalt pavement under dynamic loading. For this purpose, the wheel-tracking test was carried out on ordinary and nano-$TiO_2$ modified hot mix asphalt samples. The results of their study illustrated that using nano-$TiO_2$ in asphalt binder samples caused to an improvement in rutting depth in comparison with the ordinary mixtures [4]. Ghafarpoor et al. carried out comparative rheological tests on bitumen and mechanical tests on asphalt mixtures containing unmodified and nanoclay modified bitumen. Results showed that nanoclay could improve properties of asphalt mixtures such as stability, resilient modulus, and indirect tensile strength [5]. Golestani et al. evaluated Performance of bitumen modified with nano-composite. The physical, mechanical and rheological properties of original bitumen, and bitumen modified with nano-composite have been studied and compared. The results showed that nano-composite could improve the physical properties, rheological behaviors and the stability of the bitumen [6]. Vandeven 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 nanoclay, although it was improved its short-term and long-term hardening. In the second case, viscosity of bitumen was increased after adding nanoclay [7]. Ghasemi et al. evaluated the potential benefits of nano-$SiO_2$ powder and SBS for the asphalt mixtures used in pavements. Five bitumen formulations were prepared by using various percentages of SBS and nano-$SiO_2$ powder. Then, Marshall samples were prepared by the modified and unmodified bitumen. The results of this investigation indicated that the asphalt mixtures modified by 5% SBS plus 1% nano-$SiO_2$ powder could give the best results in the tests [8]. Khodadadi et al. investigated the effect of adding Nanoclay on long-term performance of asphalt mixtures. Indirect tensile test was conducted on cylindrical specimens made of conventional and modified bitumen at the stress levels of 200, 300, 400 and 500 kPa. The results showed that the addition of 1% nanoclay could increase the fatigue life of the asphalt mixtures [9]. The aim of this study is to evaluate the influence of nano-$TiO_2$ on the engineering properties of bitumen and asphalt concrete mixtures. For this purpose, penetration, softening point, ductility, and rotational viscometer (RV) tests were performed on modified bitumen by four different content of nano-$TiO_2$ and repeated load axial (RLA), and indirect tensile fatigue (ITF) tests on asphalt concrete mixtures by three different content of nano-$TiO_2$. With the experimental results and the numerical analysis with Matlab Software, experimental models were proposed to predict creep behavior and fatigue performance of both conventional and modified asphalt mixtures with optimum nano-$TiO_2$ for different conditions depending on temperature and stress.

## 3. Experimental procedure

### 3.1. Materials

The aggregates used in this study were graded using the continuous type IV scale of the AASHTO standard [10], which is presented in Table 1.

This study has used 60/70 penetration grade bitumen was obtained from Isfahan Mineral Oil Refinery, Isfahan, Iran, whose properties are shown in Table 2 [11]. Also, Properties of nano-$TiO_2$ are shown in Table 3.

### 3.2. Sample preparation

Nano-$TiO_2$ is added as admixture to bitumen (1%, 3%, 5%, and 7% by weight of bitumen). Preparation of asphalt samples (mixing of bitumen and aggregate) is performed at temperature 150 °C which covers the changes of the bitumen viscosity. The Marshall test was carried out according to ASTM D1559 to determine the optimum bitumen content of asphalt concrete mixtures containing different percents of nano-particles. Specimens were prepared with optimum nano-content. The optimum content of nano was also determined according to Figs. 2–5. 5% nano-$TiO_2$ is optimum percentage for the particular mixture which is used in this research.

**Table 1**
Gradation of aggregates used in the present study.

| | | | | | | |
|---|---|---|---|---|---|---|
| Sieve (mm) | 19 | 11.5 | 4.75 | 2.36 | 0.3 | 0.075 |
| Lower–upper limits | 100 | 90–100 | 44–74 | 28–58 | 5–11 | 2–10 |
| Passing (%) | 100 | 95 | 59 | 43 | 13 | 6 |

**Table 2**
Properties of bitumen used in this study.

| Test | Standard | Result |
|---|---|---|
| Penetration (100 g, 5 s, 15 °C), 0.1 mm | ASTM D5-73 | 68 |
| Ductility (15 °C, 5 cm/min) (cm) | ASTM D113-79 | 101 |
| Solubility in trichloroethylene (%) | ASTM D1041-76 | 99.5 |
| Softening point (°C) | ASTM D36-76 | 51 |
| Flash point (°C) | ASTM D91-78 | 250 |
| Loss of heating (%) | ASTM D1754-78 | 0.1 |
| Viscosity at 135 °C (Pa s) | ASTM D4402 | 0.53 |

**Table 3**
Properties of nano-$TiO_2$ used in this study.

| Specification | Result |
|---|---|
| Molecular formula | $TiO_2$ |
| SSA ($m^2$/g) | 50 |
| Color | White |
| Particle size (nm) | 20 |
| Bulk density (g/$cm^3$) | 0.08 |
| Purity (%) | 99.5 |
| Morphology | Spherical |

### 3.3. Laboratory tests

#### 3.3.1. Empirical rheological tests on bitumen

To determine the optimum content of nano-$TiO_2$ for bitumen, penetration, softening point, ductility, and rotational viscometer (RV) tests were carried out on conventional and modified bitumen with different nano-$TiO_2$ content. The selected nano-$TiO_2$ content were 1%, 3%, 5%, and 7% by weight of bitumen. The modification of bitumen with nano-$TiO_2$ was performed at nano-scale level by thermodynamic driving force. 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. Rotational viscometer test, as described in ASTM-D4402, is used to measure the apparent viscosity of bitumen from 38 to 160 °C. The torque on the apparatus-measuring geometry, rotating in a thermostatically controlled sample holder containing a sample of bitumen, is used to measure the relative resistance to rotation. The torque and speed are used to determine the viscosity of the asphalt in Pascal seconds. In this study, rotational viscometer test is done on 135 °C.

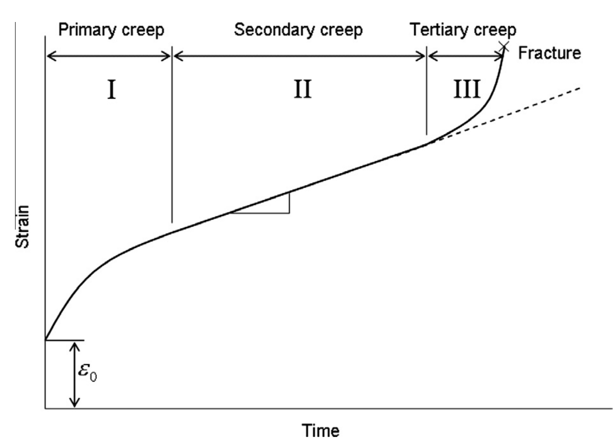


**Fig. 1.** A typical creep curve.