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# Investigation on the Effect of Titanium Oxy di-fluoride (TiOF2) Nanoparticles on the Rutting Behavior of Asphalt Mixtures

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**ABSTRACT:** Rutting is one of the main reasons for reducing the life of the asphalt pavements. Asphalt binder modification using various additives is one of the most common methods for rutting reduction and asphalt modification. Many materials such as oils, ashes, polymers, and nanomaterials are used in asphalt binder to improve asphalt mixtures. In this paper, physical and rheological properties of asphalt mixture modified by titanium oxy di-fluoride (TiOF2) nanoparticles as an additive were investigated. The degree of penetration and the softening point tests on the control and modified asphalt binder showed increasing nanoparticles amount caused an increment in the softening point and decrement the degree of penetration due to friction increasing between needles and bitumen. Rheological properties were investigated by Dynamic Shear Rheometer (DSR) test on the control, modified asphalt binders and the asphalt binders obtained from the rolling thin film oven test. Repeated Load Axial (RLA) Test were performed to study the rutting properties of asphalt mixtures. The results showed that the addition of titanium oxy di-fluoride nanoparticles (gray titanium nanoparticles) to the asphalt binder increased the resistance of shear deformation and improved the elastic behavior.

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## 1. INTRODUCTION

Asphalt binder as a sticky substance of asphalt mixtures plays an important role in the millions of kilometers of asphalt pavement in the world. Various modifiers such as polymers [1], oils [2], ashes [3] and etc. have been used to improve the asphalt binder. In recent years, various nanoparticles such as nano-clay [4], carbon nanotubes [5], nano-zinc oxide [6], nano-silica [7] and nano-titanium dioxide [8] have been used to improve the properties of asphalt binder and asphalt mixtures. The results primarily indicated a significant improvement in the properties of asphalt binder such as rutting and viscosity. Rutting in asphalt surface as one of the most important failures have been considered especially in tropical regions with increasing traffic volumes on the roads. Rutting in flexible pavements is measured by the sum of all permanent cumulative strains in one or more layers of the pavement. The rutting and thermal cracks depend on the intensity of the viscoelastic properties of asphalt binder and have long been used as a major criterion for designing flexible pavements. Many studies have been conducted to investigate the effect of different nanomaterials on mechanical properties of the asphalt mixture. The results showed that asphalt mixture behavior is improved. In this study, the effect of $TiOF_2$ nanoparticles on the rheological and physical properties of asphalt binder and rutting properties on asphalt mixture are investigated.

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## 2. MATERIALS AND PREPARATION

The asphalt binder used in this study is 60-70 which was produced by J-Oil Company in Isfahan. $TiOF_2$ nanoparticles were provided by Nano Arshia Company. Solutions with different concentrations of $TiOF_2$ dissolved in kerosene (1, 2, 3 and 4% by weight) were prepared. For better and uniform dispersion of nanoparticles in kerosene, they were agitated for 5 minutes with a mechanical stirrer with 5000 rounds and then placed in an ultrasonic bath at 60 °C for 45 minutes. As well as, an anionic active surface (a mixture of 5% weight/weight of the surfactant/nanoparticles) was used to prevent the deposition of nanoparticles. The asphalt binder was heated to 170 °C to mix the solution with asphalt binder. Then, the solution containing nanoparticles was added and stirred at a speed of 3500 rpm for 1.5 hours to evaporate the existing kerosene in addition to the proper dispersion in the asphalt binder. Finally, the control and modified bitumen was mixed whit aggregate and asphalt mixture were made.

## 3. EXPERIMENTS

X-ray spectroscopy technique is used for elemental analysis and phase determination of $TiOF_2$. To check the physical properties of original and modified asphalt binder, general tests including needle penetration at 25 °C according to ASTM-D5 standard and softening point according to the ASTM-D36 standard were used. The viscosity of the samples is also measured at 120, 135, 150 and 165 degrees, according to the standard (ASTM-D4040) standard. In order to evaluate the rheological properties of original and modified asphalt binder, a dynamic shear rheometer test was used in this research. Measuring the complex modulus (G*) and phase angle sinus (SINδ) in high temperature were performed according to the standard (ASTMD7175--08). Performing the dynamic shear rheometer test asphalt binder (AASHTO T 240). The RLA test was used to evaluate the effect of modifying asphalt binder as TiOF2 against permanent deformation behavior of asphalt mixtures. Cylindrical samples with a diameter of 101 mm and a height of 70 mm were tested by applying dynamic stresses of 100, 200 and 300 for 1 h at 40, 50 and 60 °C temperatures. In this test, each sample was subjected to a tight stress of 101 kpa at 600s and then, after removing tight stress, the stresses of 100, 200 and 300 kpa in 1000 cycles, which consisted of 1 s period loading and 1 s period unloading, were applied to it.

## 4. RESULTS AND DISCUSSION

The softening point actually reflects the viscosity of asphalt binder. The higher the softening point, the viscosity of the asphalt binder will be more. Asphalt binder with a higher softening point is less sensitive to temperature changes. The softening point increases with increasing the percentage of nanomaterial. An increase in the percentage of nanoparticles is likely to increase the friction between the needle and the asphalt binder and prevent the needle penetration. Also, increasing the percentage of nanoparticles will increase the friction between nanoparticles and asphalt binder chains, as well as increased bursts between asphalt binder hydrocarbon chains, so the softening point or hardness of asphalt binder increases. The penetration test is used to determine the relative hardness of asphalt binder. it is clear that increasing the percentage of nanoparticles leads to a decrease in the penetration grade. Reducing the degree of penetration at ordinary and high-temperature, fluidity decreases and the rigidity of asphalt binder increases. It can be concluded that the change in the softening point and the viscosity results in changes in the high temperature, which is the high-temperature sensitivity of the asphalt binder that differs for different asphalt binders.

To show the relationship between viscosity changes with temperature, the power function was used. The results showed that the correlation coefficient obtained in this study is greater than 0.99 in all samples of asphalt binder. The addition of nanoparticles to 3% gradually increases the viscosity due to the presence of friction of nanoparticles with asphalt binder chains and also with them. At high temperatures for different percentages of nanoparticles, viscosity approaches the viscosity of the main asphalt binder.

Superpave rutting factor (G*/SIN) was used to investigate the asphalt binder properties against permanent deformation in both modified asphalt binder and original asphalt binder. The results show that increasing the concentration of nanoparticles increases the rutting resistance factor of asphalt binder samples. The use of nanoparticles increases the friction between nanoparticles and asphalt binder chains as well as between asphalt binder chains with each other. These conflicts increase the resistance of asphalt binder chains to external forces and resistance against deformation and rupture. Therefore, the addition of nanoparticles improves the rutting factor. Samples containing 3% of nanoparticles exhibit the best performance against rutting. The use of higher nanoparticles resulted in a severe decrease in the gradient of improving physical properties, probably due to the bonding of nanoparticles to each other and the increase in their aggregates, which leads to the creation of stress concentration points and areas susceptible to rupture and rutting. Therefore, the concentration of 3% nanoparticles was chosen as optimal concentration. The results of asphalt binder experiments on RTFO asphalt binder are used to predict short-term aging. The rutting factor is generally reduced in all samples with increasing temperature. The rutting parameter for control and modified RTFO asphalt binders due to the more hardness of asphalt binder, in this case, is more than the main asphalt binder. RTFO asphalt binders containing nanoparticles have a higher rate of rutting factor in all percentages. By increasing the amount of nanoparticles, the rutting properties of the asphalt binder improve. Asphalt binder containing 3% of nanoparticles compared to control and other modified RTFO asphalt binders experience a greater rutting factor.

The result of RLA test shows in Figure 3, that the unmodified asphalt mixture has a more permanent deformation compared to the modified asphalt mixture. For each temperature and stress, the final strain rate for the mixture was less than the base mixture. The addition of $TIOF_2$ reduces the final strain of the mixture and the amount of permanent changes in the asphalt mixture decreases by increasing the percentage of the additive. The high-temperature effect is due to the high sensitivity of the asphalt binder and mixture to the temperature, so that as the temperature rises, the asphalt binder adhesive between the particles of the asphalt starts flowing and in this case it cannot do its main role, which creates adhesion; thus causing permanent deformation by loading, and behavior of asphalt mixing as soon as possible becomes plastic.

## 5. CONCLUSIONS

The rutting properties of the asphalt binder improve. The least amount of rutting in asphalt binder containing 3% of nanoparticles was observed. use of $TIOF_2$ as a modifier has a great effect on the improvement of rheological and physical properties of asphalt binder.

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