Performance Assessment of Asphalt Pavement mix Modified by Nano-Silica and Nano-Clay

Abdelzaher E. A. Mostafa, Waleed M.F. Tawhed, Mohamed R. Elshahat

Abstract— In recent years, Nano Technology started to be utilized in many civil engineering applications and one emphasis was in highway pavements. Nano-materials are used to improve the quality and behavior of bitumen in different conditions. This research represents the results obtained from an experimental program designed to study the improvement of asphalt mix characteristics when using nano-materials. In this study, the nano-materials used were nano-silica, kaolinite nano-clay, and montmorlinite nano-clay by percents of (1, 3, 5, 7, and 9%) by weight of bitumen. Rheological properties of nano-modified bitumen namely; penetration, softening, flash point, and viscosity were studied. Furthermore, the mechanical properties of asphalt mixes constructed using nano-modified bitumen were studied, namely; stability, flow, compression stress, modulus of elasticity, and indirect tensile strength. From the results, it was observed that using nano-materials improve the rheological properties of bitumen in the form of decrease in penetration by 26% and increase in softening, flash point, and viscosity by 29%, 8%, and 6% respectively. In addition, nano-modified bitumen improves the mechanical properties of asphalt mix in the form of increase in stability, compressive strength, and indirect tensile strength by 37%, 40%, and 90%. Essentially, the recommended optimum percentages of nano -modified bitumen used in asphalt mix are 7% nano-silica, 9% kaolinite nano-clay, and 9% montmorlinite nano-clay.

Index Terms— Hot Asphalt Mix; Nano-Materials; Nano-Silica; Nano-Clay

I. INTRODUCTION

Bitumen is one of the main constituents of road pavements as it acts as the binding material for aggregate. Asphalt pavements should resist heavy stresses and undesirable environmental conditions for a suitable service life time, thus modifying asphalt bitumen to overcome the limitations of pure bitumen for high temperature rutting and low temperature cracking is necessary using modern materials [Lewandowski, L.H., (1994)][1].

Modification of asphalt is required to its properties such as adhesion, temperature sensitivity, friction properties, oxidation resistance, aging resistance and durability. Types of modifiers are including various resins, rubbers, polymers, sulfer, metal complexes, fibers and chemical agents [Shen, J.A., (2011)][2].

According to a joint publication of Asphalt Institute and Eurobitume in 2011, the world consumption of bitumen is about 102 million tons per year, 85% of it is used in various types of pavements [Asphalt Institute; Eurobitume, (2011)][3]. Production of bitumen is hard process and the quality of the produced bitumen depends on the crude oil sources and the refinery processes [Becker, Y. et. al., (2001)][4].

In the past few years, reconstruction and development of infrastructures in developing countries demand better efficiency and quality of bitumen. Therefore, investments in research to improve of bitumen focused on bitumen modification using nano-materials [Zhu, J. et. al., (2014)][5].

II. LITERATURE REVIEW

Yu, J. et. al., (2007) studied improvement in styrene–butadiene–styrene (SBS) polymer modified bitumen by adding montmorillonite nano-clay. It was found that addition sodium montmorillonite (Na-MMT) and organophilic montmorillonite (OMMT) increase the viscosity and the higher complex modulus and lower phase angle.[6]

Yu, J. et. al., (2007) proved that nano-clay-modified asphalt had good rutting resistance compared to pure asphalt or SBS-modified asphalt. In addition, they explained that MMT-modified asphalt may form an intercalated structure, whereas the OMMT modified asphalt may form an exfoliated structure based on the X- ray diffraction (XRD) results.[7, 8]

Mahmoud, A.A., (2012) studied the effect of add montmorlinite nano-clay (MMT) to polymer-modified bitumen prepared by (13%) polyethylene terephthalate (PET). Different mixes were prepared with 0, 3, 6, 9 % of nano-clay from PET percent. Penetration, softening, and marshall tests were conducted. The results showed that, stability and unit weight of bitumen increased by the increase in nano-clay while flow, void ratio, and VMA were decreased.[9]

Muniandy, R. et al., (2013) studied the effects of adding different dosages of organic nano-clay with (0, 3, 5, and 9%) by weight of bitumen on the different properties of asphalt. Two types of organic montmorillonite nano-clay were used (N3 and N4). The results indicated that; Nano-clay type and proportion were both significant factors affecting physical properties of bitumen while they were insignificantly affecting softening point. In addition, the results showed that nano-clay proportion had higher effects than nano-clay type on rutting of asphalt.[10]

Zafari, F. et. al., (2014) studied effects of using nano-silica on bitumen properties. Percents of 2%, 4% and 6% nano-silica by weight of the asphalt were used. Superpave™ tests, and SEM imaging were conducted. The results show that nano-silica improves the aging resistance and presence of nano-silica significantly increases the complex modulus (G*) and complex viscosity (η*) of the asphalt binder. This in turn

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improves pavement resistance to rutting.[11]

Mostafa, A.E. studied the improvement in bitumen by using nano-silica and nano carbon tube on the properties of the bitumen. Percent of 1, 3, 5, 7, 9, nano-silica and 0.01, .01, 0.5, and 1% nano carbon were used. Two methods of mixing (Mechanical Mixer and High Shear Mixer) were conducted. The results show, there was no obviously different in physical properties between types of mixing. Increase in nano percent, increase the viscosity and softening point while it is decrease the penetration. For asphalt mix, it was found that the optimum nano-silica percent was 7% while for nano carbon was 0.5%. High shear mixing in nano carbon case was better than mechanical mixing while for nano-silica it was the reverse according to the results and micro scan test. [12]

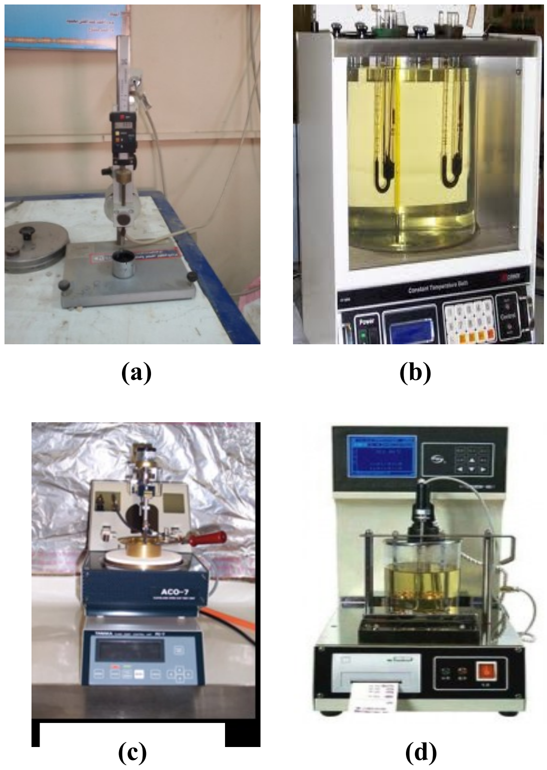
III. EXPERIMENTAL PROGRAM

Aim of this research is to study the improvement of the rheological and mechanical properties of bitumen HMA using different types and dosages of nano-materials in the laboratory. To achieve this aim, an experimental program was designed to use three types of nano-materials, namely; (nano-silica, kaolinite nano-clay, and montmorlinite nano-clay). Samples of these used materials are shown in Figure (1). Nano-materials were mixed with pure bitumen by a Mechanical mixer as shown in Figure (2). To evaluate the improvement in rheological and mechanical properties of nano-modified bitumen standard ASTM tests were performed. The rheological tests performed are; penetration (ASTM-D5), softening point (ASTM-D36), viscosity (ASTM-D4402), and flash point (ASTM-D3143-13). The used equipment for the rheological experiments are shown in Figure (3). The mechanical experiments performed on the asphalt specimens are; marshall test (ASTM D5581 - 07a), unconfined compression test (ASTM-D2166), and Indirect tensile test (ASTM-D6931) as shown in Figure (4). Asphalt mix design was performed to determine the optimum percent of pure bitumen in the asphalt mix according to Marshall design method.

(a) (b) (c)

Figure 1: Samples of the Nano-Materials Used in this Research; (a) Nano-Silica, (b) Kaolinite Nano-Clay, and (c) Montmorlinite Nano-Clay

Figure 2: Mechanical Mixer



(a) (b)

(c) (d)

Figure 3: Rheological Properties of Bitumen; (a) Penetration, (b) Viscosity, (c) Flash Point, (d) Softening

(a) (b)

Figure 4: Mechanical Tests for Asphalt Specimens; (a) Marshall Test, (b) Unconfined Compression Test

IV. RESULTS

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Figures (5) to (8) show the improvements of bitumen rheological properties by increasing the percent of nano-material. Figure (5) represent the effect of nano-materials on penetration degree. From the figure, penetration degree is inversely proportional with the increase of nano-material. At 9% nano, penetration decrease by 26.15%, 23.08%, and 13.85% for nano-silica, kaolinite nano-clay, and montmorlinite nano-clay respectively. Before 4% kaolinite nano-clay is the best in decreasing penetration while after this percent effect of nano-silica increase to be the best because of the rate of decreasing in penetration in case of nano-silica is much than the rate in case of montmorlinite nano-clay.

Figure (6) show the effect of nano-materials on softening. From the figure, softening is directly proportional with the increase of nano-material. At 9% nano, softening increase by 29.17%, 27.08%, and 16.67% for kaolinite nano-clay, nano-silica, and montmorlinite nano-clay respectively. Effect of nano-silica and kaolinite nano-clay is nearly the same at percents 1, 7, 9%.

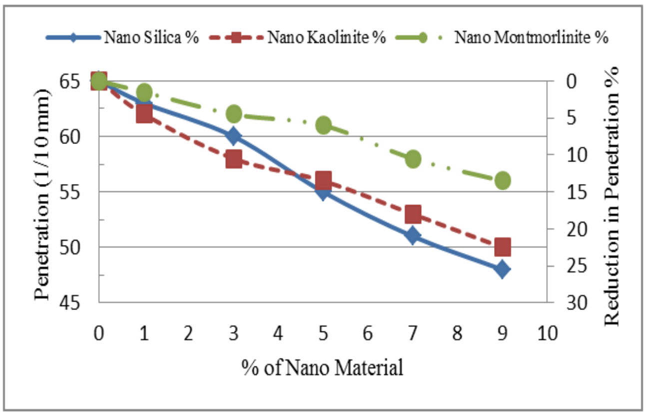

Figure 5: Effect of Nano-Materials on Penetration Degree

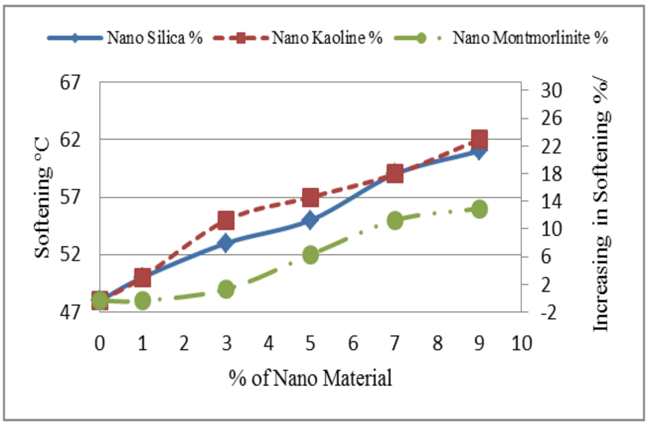

Figure 6: Effect of Nano-Materials on Softening

Figure (7) show the effect of nanomaterials on flash point. From the figure, flash point is directly proportional with the increase of nano-material. At 9% nano, flash point increase by 8.33%, 6.25%, and 5% for kaolinite nano-clay, montmorlinite nano-clay, and nano-silica respectively. Rate of flash point increasing for nano-silica is lower than the rate of nano-clay.

Figure (8) show the effect of nano-materials on viscosity. From the figure, viscosity is directly proportional with the increase of nano-material. At 9% nano, viscosity increase by 6.44%, 3.92%, and 3.36% for nano-silica, kaolinite nano-clay, and montmorlinite nano-clay respectively.

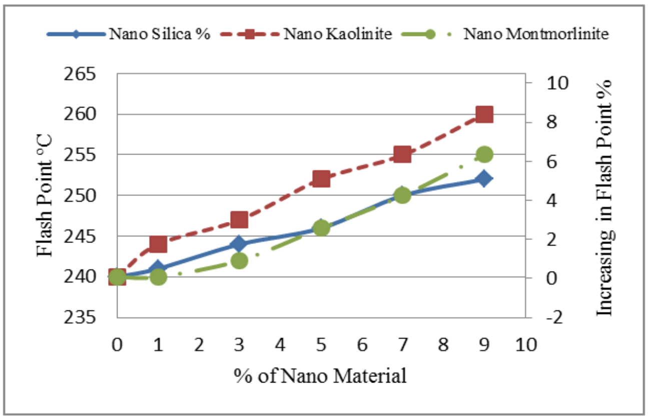

Figure 7: Effect of Nano-Materials on Flash Point

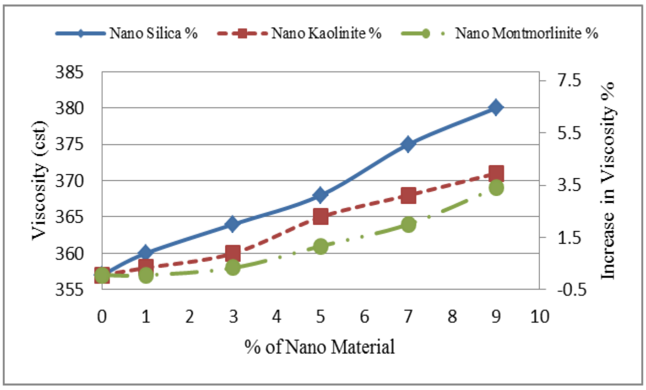

Figure 8: Effect of Nano-Materials on viscosity

Optimum bitumen percent for asphalt mix is 5.5% obtained from Marshall mix design as shown in Figure (9). Figures (10) to (17) show the effects of nano modified bitumen on the mechanical properties of asphalt mix. From all figures, optimum percent of using nano-materials depends on the type of nano-materials. In case of nano-silica optimum point is 7%, while in case of kaolinite nano-clay or montmorlinite nano-clay is 9%. Figure (10) show the effect of nano-materials on stability. Stability is directly proportional with the increase in nano percent. Effect of nano-silica and kaolinite nano-clay on the stability nearly is the same with similar increasing rate which is higher than montmorlinite nano-clay. From results, stability increase by 31.75% for (7%) nano-silica, and 37.5%, 17.6% for (9%) kaolinite nano-clay and montmorlinite nano-clay respectively.

Figure (11) show the effect of nano-materials on flow. Flow is inversely proportional with the increase in nano percent. Effect of nano-silica and montmorlinite nano-clay on the flow nearly is the same while kaolinite nano-clay has higher effect than them. From results, flow decrease by 13% for (7%) nano-silica, and 21%, 13.65% for (9%) nano kaolinite and montmorlinite respectively.

Figure (12) show the effect of nano-materials on air voids. Air voids is inversely proportional with the increase in nano percent. There is no effect for nano-material type on air voids under 3% nano percent. From figure, air voids decrease by 13% for (7%) nano-silica and 17.13%, 15.5% for (9%) nano kaolinite and montmorlinite respectively. From results, effect of nano-materials type on the air voids is non-significant.

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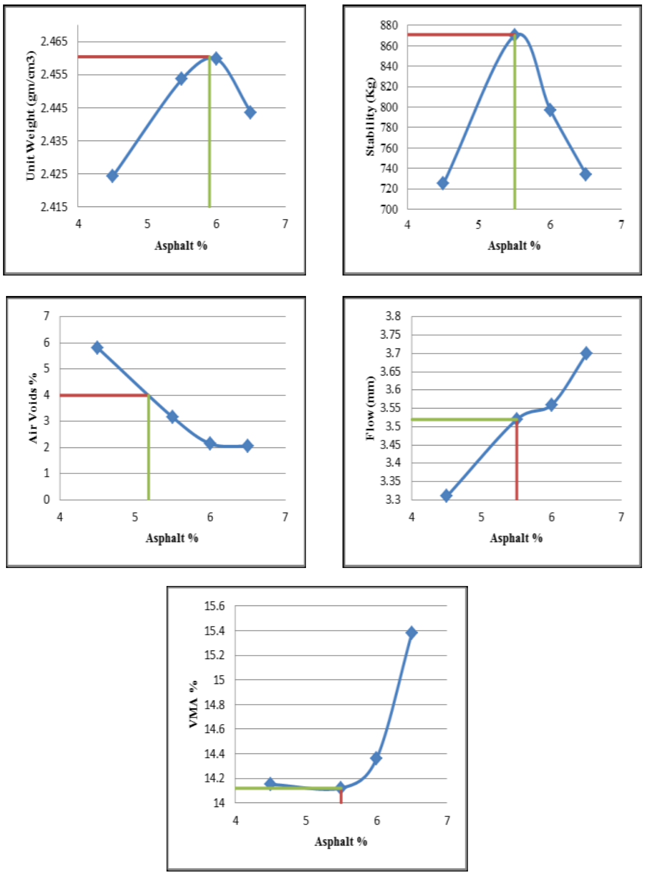

Figure 9: Marshall Mix Design

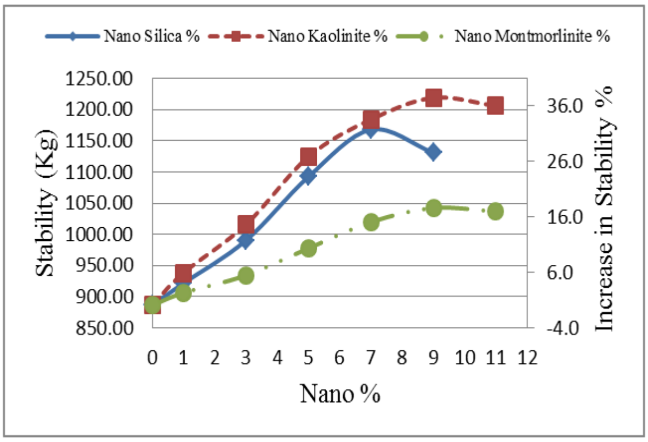

Figure 10: Effect of Nano-Materials on Stability

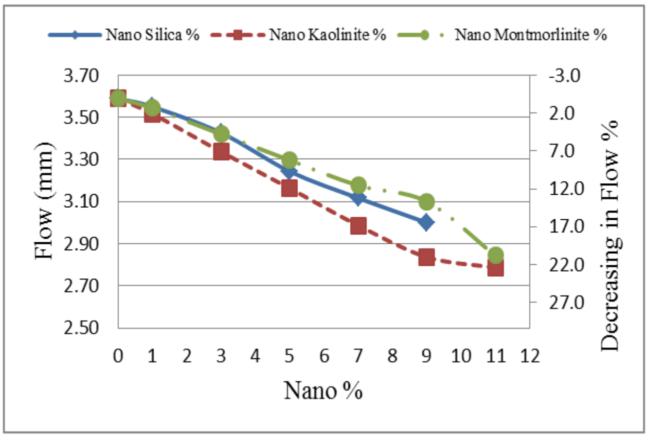

Figure 11: Effect of Nano-Materials on Flow

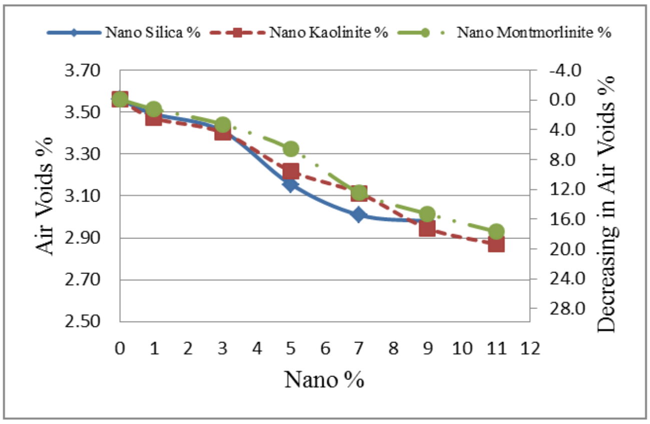

Figure 12: Effect of Nano-Materials on Air Voids

Figure (13) show the effect of nano-materials on VMA. VMA has the same behavior of air voids. VMA decrease by 3.4% for (7%) nano-silica and 3.7%, 3.3% for (9%) nano kaolinite and montmorlinite respectively.

Figure (14) show the effect of nano-materials on unit weight. Unit weight is directly proportional with the increase in nano percent. Unit weight increases by 0.57% for (7%) nano-silica and 0.61%, 0.53% for (9%) nano kaolinite and montmorlinite respectively. From results, effect of nano-materials type on the unit weight can be neglected.

In addition, Figure (15) show the effect of nano-materials on compression stress. Kaolinite nano-clay with percent more than 3% has a positive effect on the compression stress with max percent of increasing 41.14%. Otherwise montmorlinite nano-clay has a negative effect on the compression stress. While just 7% nano-silica has a positive effect on the compression stress by 29.4%.

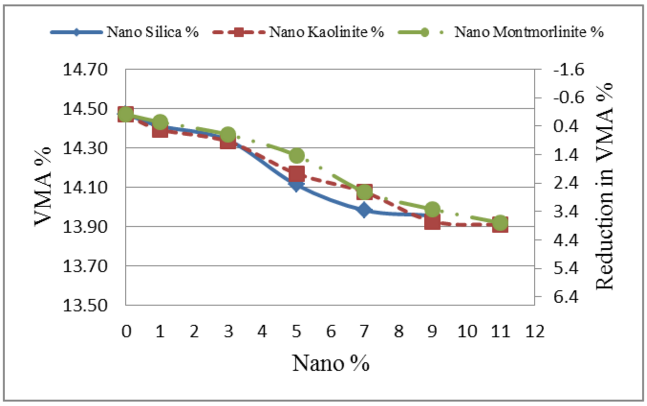

Figure 13: Effect of Nano-Materials on VMA

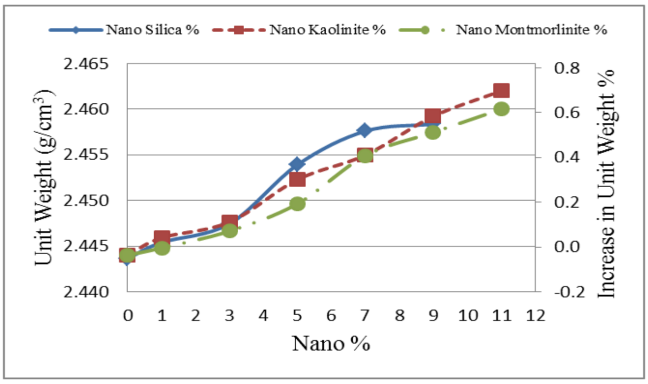

Figure 14: Effect of Nano-Materials on Unit Weight

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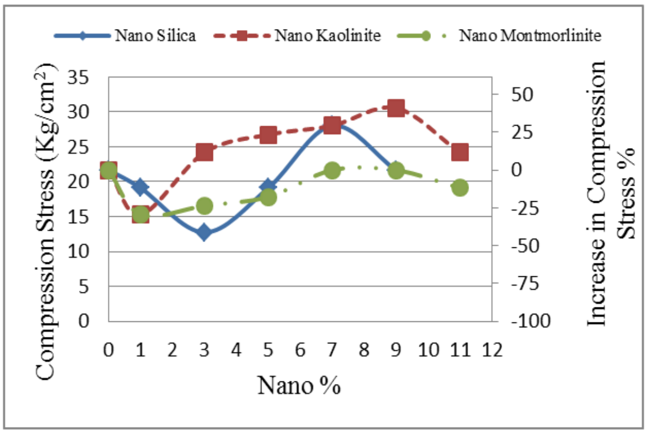

Figure 15: Effect of Nano-Materials on Compression Stress

Figure (16) show the effect of nano-materials on modulus of elasticity. Modulus of elasticity has the same behavior as the compression stress. Modulus of elasticity increases by 19% for (7%) nano-silica, and 41.8%, 3.5% for (9%) nano kaolinite and montmorlinite respectively.

Figure (17) show the effect of nano-materials on the indirect tensile strength. Indirect tensile strength increases by 50% for (7%) nano-silica, and 93.5%, 40.65% for nano kaolinite and montmorlinite respectively.

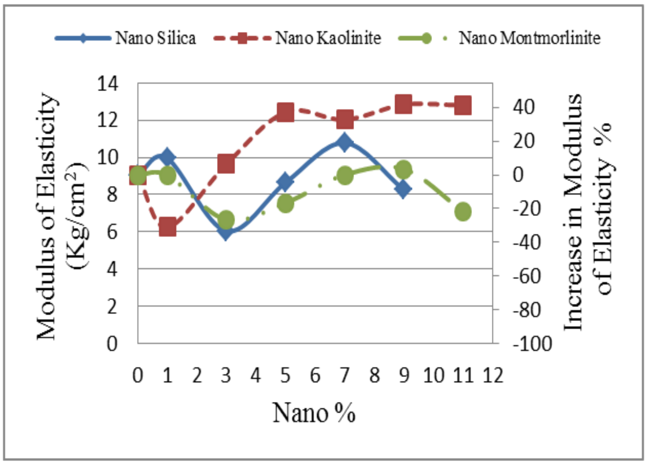

Figure 16: Effect of Nano-Materials on Modulus of Elasticity

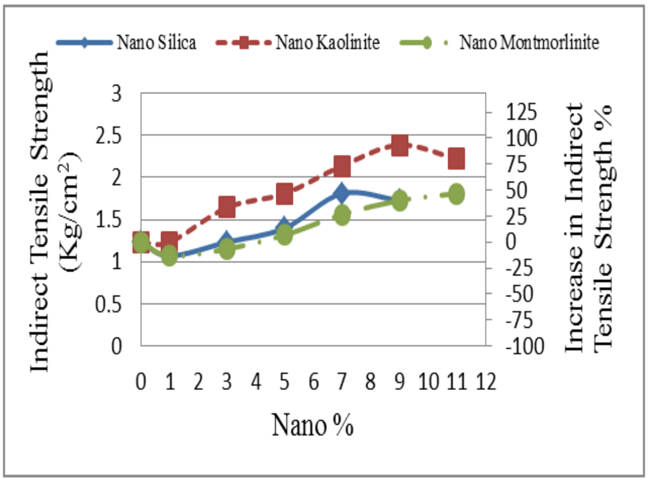

Figure 17: Effect of Nano-Materials on Indirect Tensile Strength

V. CONCLUSIONS

Based on the results obtained from this research, the following conclusions can be drawn:

1) Nano materials improve the rheological properties such as decrease penetration and increase each of softening, flash point, and viscosity.
2) Nano silica is the best in each of penetration and viscosity by 26.15%, and 6.44%respectively, while nano kaolinite is the best in each of softening and flash point by 29.17%, and 8.33% respectively.
3) Optimum percent of nano modified bitumen is (7%) for nano silica, and (9%) for each of nano kaolinite and montmorlinite.
4) Nano material improve the mechanical properties of the asphalt mix such as increase each of stability, unit weight, modulus of elasticity, and indirect tensile strength while it is decrease each of flow, air voids, voids in mineral aggregate.
5) Percent of nano material less than nearly 3% has a negative effect on the compression stress, but for more than 3% it has a positive effect.
6) Nano kaolinite is the best material which increases each of stability, unit weight, compression stress, modulus of elasticity, and indirect tensile strength by 37.5%, 0.61%, 41.14%, 41.8%, and 93.5% respectively. While it is decrease each of flow, air voids, VMA by 21%, 17.13%, and 3.7% respectively.

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