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# Investigating the benefits of utilising nanomaterials in enhancing the properties of bitumen and asphalt mixtures' (Review Study)

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**Abstract**

This paper aims to review the main benefits of utilising nanotechnology and adding nano materials and its impact on enhancing bitumen characteristics and asphalts mixers properties. In modern science and technologies that based on Nano measures, a huge attention was paid to take advantage from the scale of nanometre in various apparatus, equipments and new schemes while being able to control this minor measure. For many past years, nanotechnology has been considered as an interesting topic to be studied by many researchers and engineers. These technologies have been spread wildly as nanotechnology proven its ability to enhance the life quality, and to achieve economical and environmental enhancements. Consequently, the largest countries such as Japan, US and many others paid a huge attention to invest in one of the nanotechnologies applications. The main results that this study addressed is that adding various types of nano-particles to asphalt mixtures such as nanosilica, nano-clay, and nanotubes enhances the resistance abilities of asphalt such as the rutting and fatigue resistance and enhance the asphalt binders' viscosity.

**Keywords:** Nanotechnology, nano-particles, Nano-clay; Nanotubes; Nanosilica, Asphalt mixtures.

## 1- Introduction

Greek and Latin words are the main origin of various daily measurements terms, such as , the " Khilioi" Greek word is the origin of the common known world which is "Kilo" that is equalt to one thousand measure. As well as Nonnos Greek word is the basic origin of "Nano" term which reflected the meaning of "very short man". Whereas as (Allhoff, Lin, Moore, 2010) clarified the same term in scientific dictionary indicated a very small measurement unit which is equal to one-billionth (0.000 000 001) of the base unit.

In modern science and technologies that based on Nano measures, a huge attention was paid to take advantage from the scale of nanometre in various apparatus, equipments and new schemes while being able to control this minor measure (Motlagh et al., 2012).

According to Kelsall et al. (2005), Nano meters measures and features were utilised hugely in various constructing, and designing applications. Nanotechnology allows the design of systems with high sensitivity, effective functionality, high resistance to strain forces, and many other. All aspects are directly the result of the small dimensions of nano-particles (Teizer et al., 2012).

Physical nano-scale characteristics and microstructure are the main features that control the macroscopic mechanical behavior of bituminous materials, despite the fact that these materials widely used in road construction applications (Partl, Gubler, Hugener, 2004).

For several past years, nanotechnology has become the main concern of different engineers and researchers all over the world. These technologies have been spread wildly as nanotechnology proven its ability to enhance the life quality, and to achieve economical and environmental enhancements (Motlagh et al., 2012). Consequently, the largest countries such as Japan, US and many others paid a huge attention to invest in one of the nanotechnologies applications. Therefore, this study came to investigate the nonmaterial' applications and investments in road construction and especially in pavement appliance for the purposes of enhancing the physical and mechanical properties of pavements.

2. The relation of adding nanomaterials in asphalt mixes and its impact on asphalt performance**:**

An item that is recognised with nano term represents a highly minimized item that owns at least between 1 and 100 nanometers in size dimension. Chemical and physical characteristics of materials with nano-size hugely differs from ordinary items characteristics and this could be explained according to the well-recognised difference in area-to-volume surface ratio of such particles, additionally to the quantum influences with regard to the spatial retention (Teizer et al., 2012). According to the previous related literature, the nano-clay particles could be considered as the basic ingredients that may be added to develop the applications of asphalt construction practices.

***2.1 Nano-clay:***

Nano-clay particles have been considered as an interesting topic to be studied by a wide range of researchers in the past years (Jahromi and Ghaffarpour, 2009, Polacco et al., 2008, Van de Ven et al., 2008). The main feature that distinguishes clay material that is used in nano-clay particles is its harmony with organic monomers and polymer applications. The composites that made of nano materials basically includes various types of polymers and layers of silicate materials.

Nano-clays have an intensive interaction with the bitumen, with regard to clay discs from separating action which may generate nono-clay materials that have a surface area that is considered large and could reach to 800 $m^2$/g (Yang, Tighe, 2013). Bitumen viscosity and bitumen is hugely affected by the type of added montmorillonite nano-clay as discussed by Van de ven et al. (2008). Though, the bitumen aging resistance, either in short or long term, were enhanced through the addition of one of the nano-clay material at least. Moreover, modifying bitumen with nano-clay materials even in minor quantities can enhance various physics properties such as: asphalt stiffness characteristics, tensile modulus and strength abilities, higher flexural strength, and thermal stability conditions. Generally, bitumen with nano-clay additions has high rates of elasticity than other original bitumen material. On the other hand, bitumen materials that modified with nano-clay materials have a lower mechanical energy the non-modified bitumen (Jahromi and Ghaffarpour, 2009).

The composites of polymic nanos is considered as one of the most essential and useful newly discovered materials. Generally, polymer modified nano-clay has higher quality physical properties characteristics (Jahromi and Ghaffarpour, 2009).

Moreover, both the Organophilic Montmorillonite (OMMT) and the Sodium Montmorillonite (NA-MMT) have potential chances to reduce rutting of asphalt pavements or even the permanent deformation. Nanocaly had a compatilizing effect on polymer and asphalt. Compatibility is the most important factor in the preparation of materials; a high compatibility between polymer and clay make the polymer dispersion better between the asphalt components. Thus, nano-clay influences the rheological characteristics of asphalts is also influenced by the addition of nano-clay materials (Polacoo et al., 2008)(Jahromi and Ghaffarpour, 2009).

Selecting the perfect matching clay category considered essential for the purposes of providing an efficient polymer penetration in the clays interlayer spacing to ensure generating the desired exfoliated product (Sattler, 2010). Generally organic component in the structure of intercalate entered between the layers that composed of clay through enhancing the spacing between interlayer with keeping an accepted spatial relation(Gopalakrishnan et al., 2011) (Figure1).

***2.1 Carbon nanotubes:***

Various types of allotropes can be formed by a carbon atom; graphite and diamond are the carbon allotropes, low-dimensional allotropes known as carbon nanomaterials are also formed by carbon. Examples of such nanomaterials are 1D carbon nanotubes (CNTs) (Kaushik B.K., Majumder M.K., 2015).

A Carbon nanotube defined as a one-atom sheet which is created through rolling up of sheet of grapheme into a cylinder with a diameter of the one nanometer (Figure2). Single tubes or single-walled CNTs, and coaxial tubes which are also recognised as multiple-walled CNTs (Figure 3) are the main two different types of CNT. Single-walled CNTs produce more strength and stiffness than multi-walled CNTs, but, multi-walled CNTs are easier to produce and less expensive (Bai, Allaoui, 2003).

When adding CNTs with a semi high rates (more than 1%) to the base bitumen then rheological properties of the bitumen (or asphalt) could be affected significantly (Xiao et al., 2011). Additionally, adding a quantity of (0.001) of carbon nanotubes to bitumen asphalt mixtures, this could improve asphalt pavement properties in addition to decrease the under layers thickness which will minimise the consumption of materials that made from stones (Motlag et al., 2012). Additionally, CNTs enhances the thermal generated cracking in addition to developing rutting resistance and reducing oxidative aging susceptibility of asphalt mixtures in long-term conditions (Santagata et al., 2012).

### *2.2 Nanosilica:*

Colloidal silica, fumed silica and silica gel are the most realised production of Silica usage in industrial applications. There are several essential applications of nanosized silica such as provision of drug and medicine (Barik et al., 2008). Furthermore, Silica nano-particles utilised widely in the mixtures of cement concrete (Quercia, Brouwers, 2010), and in other scientific areas. The continuous interest of these nanomaterials can be explained due to the high performance characteristics of the generated production in addition to its low cost (Lazzara, Milioto, 2010).

When adding nanosilica atoms within the base binder layers then the viscosity values of the original asphalt binders could be decreased slightly.

Having an asphalt binder with low viscosity indicates either lower consumption of energy or lower compaction temperature of the construction practices will be achieved. Furthermore, Adding nanosilica at the control asphalt enhanced the recovery capacity, the relaxation from stress and the properties of nanosilica modified asphalt binder was the same as the control asphalt and the low-temperature grade of nanosilica modified asphalt binder and the low-temperature of the control asphalt was the same. In addition, the fatigue performance, the anti-aging performance of nanosilica modified asphalt binder and mixture, anti-stripping property and rutting resistance were enhanced (Yao et al., 2012).

According to chin and Zhang (2012), adding nano powder rubber form the type of VP401 and with a quantity of 1% to the asphalt binder could enhance rutting and cracking resistance of low-temperature asphalt. Furthermore, moisture susceptibility under water or de-icing chemicals of asphalt mixtures could be enhanced when adding nano-clay and carbon microfiber (Goh et al., 2010). Finally, the physical in addition to the mechanical characteristics of asphalt binder and mixtures can be increased by modifying asphalt mixture by 2% nano-SiO2 powder and 5% SBS (Ghasemia et al., 2012).

## 3. Characteristics of Nano-material

There is an essential need to realise the characteristics of the nano-sized materials. But, most of the testing equipments are designed for macro-scale measurements. Thus, it is important to introduce new instruments that can be used to measure the nano-scale materials. The main examples of these instruments are Atomic Force Microscope (AFM) and Scanning Electron Microscope (SEM) (Nazzal et al., 2012).

### *3.1 Atomic Force Microscope (AFM).*

AFM basically utilised to investigate the samples surface characteristics by using atomic forces (the layout of AFM is shown in figure 4). The surface of the samples will be scanned through a sharp probe and a cantilever,

Then, when the probe is located into the surface of samples, Hooke's law works as a cantilever deflection is produced according to the generating forces between the samples and the probe. Magnetic forces, capillary, van der walls and mechanical forces are the main forces that generated through AFM (Azahar et al., 2015).

### *3.2 Scanning Electron Microscope (SEM):*

This term can be used to analyze the surface and subsurface images on nano-particles (the layout of SEM is shown in figure 5). The image of samples could be generated through producing a high energetic electrons beam through scanning process. Therefore, information about surface structure can be produced when electrons make a strong interaction with other atoms (Azahar et al., 2015).

## 4. Nanotechnology advantages in asphalt mixtures.

There are two common ways in which nanotechnologies could benefits asphalt mixtures which could be summarised as follow;

a. by creating entirely new products
b. by enhancing the durability, cost, performance effectiveness of existing products or either processes

In more details, the basic advantages of Nanotechnologies when adding to asphalt mixes are as follow;

- Enhance the UV aging resistance.
- Develop the stability of storage in polymer modified asphalt.
- Improve the asphalt durability.
- Decrease maintenance requirements.
- Decrease financial resources and energy
- Enhances the low temperatures asphalt mixes characteristics.

## 5. conclusions

Nnanotechnology applications in bituminous binder and asphalt mixture prove that this new technology can improve the pavement by achieving high performance results in durability and strength. This paper discussed three nanomaterials which are: nano-clay, nanosilica, and nanotubes. Adding nano-clay in asphalts enhances its resistance for fatigue and rutting situations, and improves the asphalt binders viscosity. Additionally, nano-clay materials could increase asphalt mixes resistance to aging. Carbon nanotubes can significantly affect rheological properties of the bitumen when they are added to the base bitumen with a considerable high rates that could be reached to more than 1%.

Moreover, Asphalt thermal cracking resistance, rutting and oxidative aging resistance could be enhanced in asphalt mixes by CNTs. Finally, it is essential to mention that adding nanosilica to asphalt mixers could improve the asphalt performance of anti-aging, rutting resistance, anti-stripping, and fatigue cracking characteristics. While, the process of adding nanosilica materials especially on the binder of control asphalt could not influence low temperature characteristics of asphalt mixes.

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## 7. Appendixes

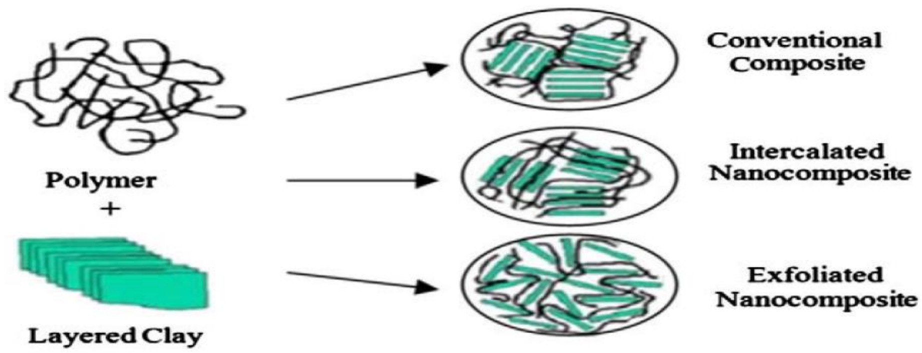


**Figure 1: Structures of nano composites polymer (Yang, Tighe, 2013).**

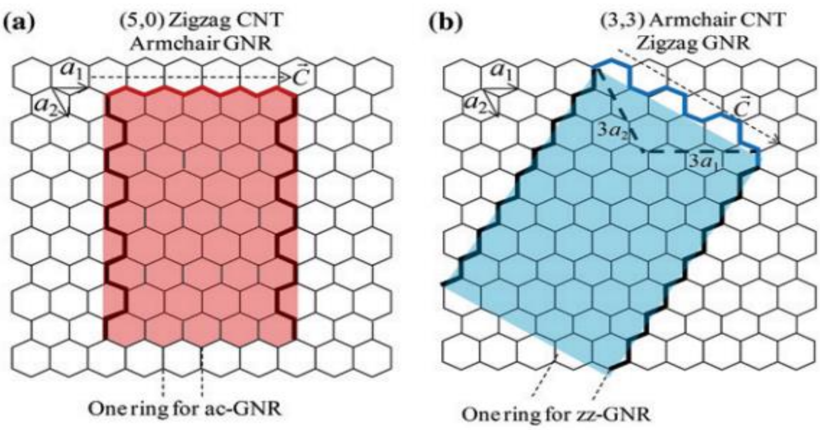


**Figure 2: graphene sheet CNT a zigzag and b armchair :Schematic view (Kaushik B.K., Majumder M.K., 2015).**

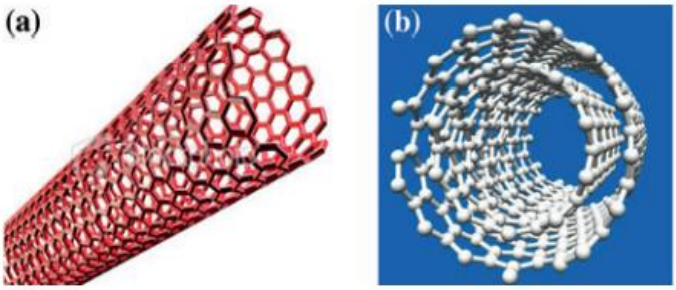


**Figure 3: CNTs (a) single-walled (b) double-walled Basic structures (Kaushik B.K., Majumder M.K., 2015).**

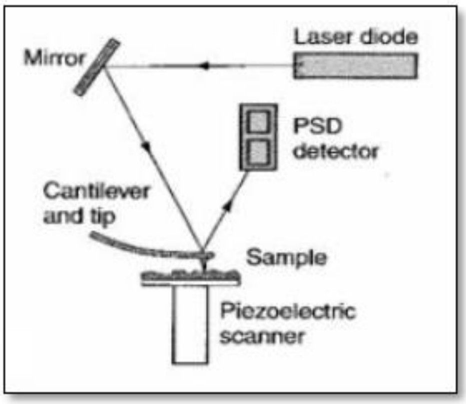


**Figure 4: AFM layout (Azahar et al., 2015).**

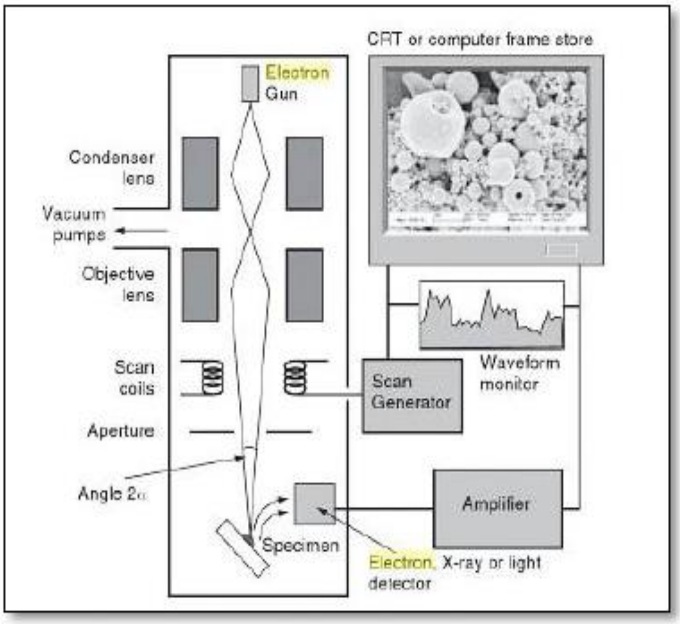


**Figure 5: Scanning Electron Microscope (SEM) layout (Azahar et al., 2015).**