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Overview of Nanotechnology in Road Engineering

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Nanotechnology has changed our vision, expectations, and abilities to control the material world. This paper examines and document applicable nanotechnology based product that can be improve the overall competitiveness of the Road engineering industry. In this review, nanotechnology is applying in road sector.

Keywords: Nanotechnology, CNT, Bitumen, Concrete, Nanosensors.

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1. INTRODUCTION

1.1 Background

Nanotechnology has recently become one of the 'hottest' areas in research and development worldwide, and has also attracted considerable attention in the media and investment community. It is essentially attention in the media and investment community. Nanotechnology helps to understand and developed new ways for road engineering at physical level.

1.2 What is Nanotechnology?

A basic definition: Nanotechnology is the engineering of functional systems at the molecular scale [8]. Nanotechnology is concerned with objects between 1 and 100 nm in size 1 nm 1×10^{-9} m. The significance and importance of controlling matter at the nano scale. At this scale common law of physics do not work, at this scale material behave like quantum dots. These materials follow only quantum law. Gaining control at nano scale structures is extraordinary like carbon nano tubes, with a tensile strength often quoted as 100 times that of steel. There are two ways to approach the nano technology:

1. Shrinking from the top down.
2. Growing from the bottom up.

These two models are fundamentally different each other for developed and creating structure.

<u>Top Down</u>

It approaches involving of reducing the size of the smallest structures towards the nano scale by machining and etching techniques.

<u>Bottom up</u>

It referred to as molecular nanotechnology, implies controlled or directed self-assembly of atom and molecules to create structures.

1.3 History of Nanotechnology

The concept of nanotechnology was put in theoretically in 1959, by Feynman. The noble prize winning physicist said that nothing in the laws of physics prevented us from arranging atom the way we want. He even pointed to a development pathway: machine that would make smaller machine suitable for making yet smaller machines, and so on- the classic 'top down' approach [8]. In 1974, Taniguchi introduced the term nanotechnology to describe precision manufacture of parts with finishes and tolerances in the range of 0.1 nm to 100 nm. In 1981, Drexler pointed out a new approach construction of materials and devices from the 'bottom up' with every atom in a designed location [8].

2. APPLICATION OF NANOTECHNOLOGY IN ROAD ENGINEERING

2.1 Road Concrete

2.1.1 Nanotechnology in Concrete

Concrete is composite of cement, water and aggregate [8]. It use in road, building and material construction. Aggregate are two type one is coarse and other is fine aggregate. Coarse aggregate is that which is bigger than 4.7 mm and fine aggregate which is smaller than 4.7 mm.

Fig. 1 – Coarse aggregate

Fig. 2 – Fine aggregate

Fig. 3 – Cement

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Concrete has relatively high compressive strength, but significantly lower tensile strength.

Why nanotechnology for concrete? Because due to the following reason:

- Improves the materials' bulk properties.
- Ability to control or manipulate materials at the atomic scale.
- To obtain thinner final products and faster setting time.
- Cost effectiveness.
- Lowered levels of environmental contamination

2.1.2 Nano Material Use in Concrete

- Carbon nano tubes.
- Nano-silica.
- Polycarboxylates.

2.1.2.1 Carbon Nano Tubes

Carbon nano tubes are molecular-scale tubes of graphitic carbon with outstanding properties. They can be several milli meters in length and can have one "layer" or wall (single walled nano tube) or more than one wall (multi walled nano tube)

2.1.2.1. A Properties

- CNT is also highly flexible.
- Mechanically, CNT appear to be the strongest material.
- The smaller diameters.
- Stiffest and strongest fibers

2.1.2.2 Nano-Silica

It is the first nano product that replaced the micro silica.
Advancement made by the study of concrete at nano scale has proved nano silica much better than silica used in conventional concrete.

2.1.2.2. A Properties

- High compressive strengths concrete (15 MPa and 75 MPa at 1 day; 40 MPa and 90 MPa at 28 days and 48 MPa and 120 MPa at 120 days.)
- High workability with reduced water/cement ratio.
- Use of super plasticizing additives is unnecessary.
- Fills up all the micro pores and micro spaces.
- Cement saving up to 35-45 %.

2.1.2.3 Polycarboxylates

Polycarboxylates or polymer based concrete admixtures are High Range Water Reducing admixture (HRWR). Low dosage-reduce water as much as high dosage of conventional admixtures. Higher dosage-produce Self Compacting Concrete (SCC).

This admixture type is very suitable for underwater anti-washout concrete.

2.1.2.3. A Properties

- Resistance to compression – 40 to 90 MPa in 1 day. Resistance to compression from 70 a 100 MPa (or more) in 28 days.
- Produces high resistance even with low addition (1 to 1.5 % of the cements weight) and gives self compacting characteristics with higher proportions (2.5 %).
- Meets the norms of environmental protection.
- 70 % less use of additives as traditional silica, super plasticizers or traditional fibers.

2.1.3 Nanotechnologies Help to Improve Road Concrete?

2.1.3.1 Addition of Nanomaterials into Concrete Could Improve its Performance

By adding nano aggregate like nano silica or sol-gel in concrete will increase the performance, life period, binding and compressive strength. M. Collepardi at University of Illinois. Investigated the concrete by adding nano aggregate in concrete 2 % nano silica, 1.5 % super plasticizer, 1 % Carbon nanotubes. This Composition of aggregate in concrete will increase the 28 Days life of concrete and 55 MPa from normal concrete [7].

Table 1 – Comparison between normal concrete and nanomaterial concrete

Hardness Tests	Normal concrete	Nanomaterial concrete
Compressive Strength	34 Mpa	55 MPa
Modulus of Elasticity	41 Mpa	42.8 MPa
Split of Tension	31 Mpa	32.3 MPa
Flexural Strength	0.83 Mpa	0.86 MPa

2.1.3.2 Addition of Nano Material into Concrete Could Decrease Efflorescence and Corrosion

By adding of nano aggregate like TiO_2 and Li will decrease efflorescence and corrosion. U.S.A base company Convergent Concrete Experiment on efflorescence and corrosion and make low alkali [4]. They originate a Concrete which have resistance against corrosion by using nano aggregate. The following Reaction proofs it.

Simple Reaction in concrete which produce Corrosion or efflorescence when calcium hydroxide react with carbon dioxide produce calcium carbonate and water and produce Corrosion product for concrete

$$Ca(OH)_2 + Co_2\text{-} > CaCo_3 + H_2O$$

After Adding Nano aggregate in Concrete Reduce efflorescence and corrosion.

Lithium Carbonate react with calcium hydroxide and produce lithium hydroxide and calcium carbonate which one is stable produce. When calcium carbonates react with titanium dioxide nano tubes produces $TiCa_3$, carbon dioxide and ozone. Lithium Carbonate with Carbon dioxide and water and produce lithium hydrogen carbonate. These $TiCa_3$ and lithium hydrogen carbonate which are more stable product which reduce corrosion.

$$Li_2Co_3 + Ca(OH)_2 -> 2LiOH + CaCo_3$$

$$3CaCo_3 + Tio_2 -> TiCa_3 + 3Co_2\ O_3$$

$$Li_2CO_3 + CO_2 + H_2O \rightarrow 2LiHCO_3$$

And $TiCa_2$ is stable and great binder product which reduces corrosion.

2.1.3.3 Addition of Nanomaterial Into Concrete Could Increase Ductility

Current research is being carried out to investigate the benefits of adding CNT's to concrete. The addition of small amounts (1 % wt) of CNT's can improve the mechanical properties [5]. Show the best improvements both in compressive strength (+ 25 N/mm^2) and flexural strength (+ 8 N/mm^2) compared to the reference samples without the reinforcement.

Table 2 – Comparison between Normal concrete and Nanomaterial concrete

Hardness Tests	Normal concrete	Nanomaterial concrete
Compressive Strength	34 Mpa	59 Mpa
Split of Tension	31 Mpa	32 Mpa
Flexural Strength	0.83 MPa	8.83 MP

2.1.3.4 Addition of Nanomaterial Into Concrete Could Reduce Carbon Emission

Globally Cement Produce 1.6 bn tones Co_2 per year. By adding nano aggregate in concrete like C-S-H gel make a interlink bonding which break Co_2 into carbon and oxygen and reduce Co_2 emission [6, 1].

Table 3 – Comparison between normal concrete and nanomaterial concrete

Emission Test	Normal concrete	Nanomaterial concrete
Carbon dioxide	12 kg/m	9-10 kg/m

2.2 Steel Composition

2.2.1 Nanotechnology in Steel?

Steel is an alloy that consists mostly of iron and has carbon content between 0.2 % and 2.1 % by weight depend on grade [8]. There are lots of types of steels which are following:

- Carbon steel.
- Spring steel.
- Alloy Steel.
- Maragin steel.
- Stainless steel.
- Weatherin steel.
- Tool steel.

2.2.2 How Nanotechnology Improve Steel Composition?

Fig. 4 – Stainless Steel

Steel is a major construction material. Its properties are such as strength, corrosion resistance, weld ability and low cost. That new steel was developed by American Iron Steel Institute and US Navy with higher corrosion-resistance and weld ability and Sandvik nanoflex™ developed ultra high strength and low cost by adding copper nano particles and carbon nano tubes at the steel [3].

Table 4 – Comparison between normal steel and nanomaterial steel

Hardness steel test	Normal steel	Nanomaterial steel
Tensile Strength	$(1/64)(d^2)$ where d is diameter	$(1/64)(d^2)(10)$ where d is diameter
Split of Tension	250 N/m	2500 N/m
Modulus of Elasticity	20×10^2 N/m	20×10^4 N/m

2.3 Coating at Bitumen Road

2.3.1 What is Bitumen?

Bitumen is a mixture of organic liquid that are highly viscous, black sticky, entirely soluble in carbon disulfide and composed primarily of highly condensed poly cyclic aromatic hydrocarbons [8]. Naturally occurring from crude oil.

Fig. 5 – Bitumen

2.3.2 How Nanotechnologies Improve Coating of Bitumen Road?

It is one of the major applications of nanotechnology in construction. For example, TiO_2 is used to coat glazing because of its sterilizing and anti fouling properties. The TiO_2 will break down and disintegrate organic dirt through powerful catalytic reaction. Furthermore, it is hydrophilic, which allow the water to spread evenly over the surface and wash away dirt previously broken down [3]. Other special coatings also have been developed, such as anti-fraffiti, thermal control, energy sawing, anti reflection coating, durability, fracture resistance and also help to increase ground level of water [1].

$$Ca + No_2^{-uv\ radiation} + Tio_2 + H_2O > Ca(No_3)_2 + H_2O$$

$Ca(No_3)_2$ is cleaning agent which can easily clean the road and remove dirt and pollution from road and increase the life of roads. Working of Bitumen at nano level make it the cross linked Integra base of bitumen which increased average molecular weight of bitumen and also increase compressive strength, tensile strength, stability, fatigue, adhesion and temperature susceptibility.

2.3.3 Nanotechnologies as Binding Agent for Bitumen Road

Different modifiers have been used by researchers for modification of bitumen binder in construction and maintenance of roads. One of the most common is polymer modifier, which is being used now at commercial level in overlays of roads, highways and bridges. These modifiers have demonstrated the improved physical and mechanical properties of asphalt and its mixes at low and high service temperatures. However, polymer modifiers are expensive and, therefore, using them as modifiers increases construction costs of the pavements significantly. In order to overcome these shortcomings, researchers have recently suggested the use of nanoclays (NC) as asphalt modifiers due to their abundance in nature, low cost of production, and small amounts needed for asphalt modification.

Montmorillonite (MMT) widely used nano clay in the field of Nanocomposite materials, belongs to the smectite-clay group. This nano clay exhibits a layered silicate structure that consists of one octahedral alumina sheet sandwiched between two tetrahedralsilica sheets and belongs to the 2 : 1 phyllosilicates family. The observed interlayer spacing is the result of stacking of the clay sheets [9].

Significant research work has been carried during 2010 and 2014 on modification of bitumen with different types of nanoclays [10-13].

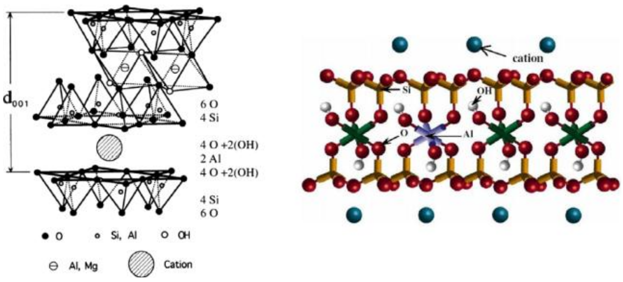


Fig. 6 – Montmorillonite nanoclay structure

When bitumen is modified with small amounts of nano clay, its physical properties are successfully enhanced on the condition that the clay is dispersed at nanoscopic level. Nano clay materials have bigger aspect ratio and a large surface area and their particles are not uniform in size and arrangement. Nanofill-15 particles are smaller in size as compared to the cloisite-15A particles. The plastic limit shows that nano clay materials are the expansive type of clay. Adding low percentages of nano clay to bitumen changes theological properties, decreases penetration and ductility and increases softening point and aging. Tests performed on binders and dense asphalt mixtures show that the cloisite-15A and nanofill-15 modifications increase the stiffness and improve the rutting resistance, indirect tensile strength, resilient modulus, and Marshall Stability. However, fatigue performance decreases at low temperatures. Also, optimum bitumen and VTM increase a little by adding nano clay.

In this work, different variables on the behavior of asphalt are investigated. These variables are asphalt content, Evaluation of the mechanical properties of asphalt concrete mixtures has revealed an enhancement in their Marshall and mechanical properties when Nanoclay was used. It was found that Marshall stability, increase as the Nano clay increase. Flow values, void ratio and voids in mineral aggregates decrease as the nano clay content increases.

This research has shown to a large extent that nano clays can be effectively used as a modifier to improve the mechanical properties of asphalt binders.

(i) The strain at failure decreases with the addition of 2 % of Nano clay and it is proved that the use of Nano clay strengthens the tensile strength properties of the asphalt binder since a lower failure strain % increases the potential for low-temperature cracking. The low temperature cracking potential of the original binder was better than Nano clays.

(ii)The original binder sample has the lowest secant modulus value when compared to the modified asphalts.

(iii) The addition of Nano clays increase the toughness of the asphalt binder relative to the original binder and the original binder do not have the toughness that the Nanoclay particles add to the asphalt.

This study reports enhanced physical properties of asphalt with the addition of modified NC. These changes in physical properties are suggested to be resulting from the increased interaction of the modified NC Si-Otetrahedralwith asphalt. These interactions were investigated using transmission FTIR experiments. The following conclusions result from these experimental studies:

(i) The physical testing results show that NC modification of asphalt enhances the physical properties of asphalt in both magnitude and nature. Dynamic mechanical analysis, flexural stiffness creep, and flexural tests were done on the NC-asphalt nano composite. Increasing NC concentration in asphalt enhances the temperature susceptibility of asphalt, as well as increasing the complex modulus, in addition to decreasing phase angle.

(ii) Increasing the NC content in asphalt to 8 %, by the weight of asphalt, and higher, significantly changes its time-dependent viscoelastic behavior.

(iii) The XRD results show significant levels of intercalation in clay galleries and increase in d100-spacing up to 43.17 Å, indicating strong interaction between asphalt and NC. The d100-spacing decreases with increasing the NC content in asphalt. These interactions are evaluated using transmission FTIR experiments.

A significant change in Si-O vibration is observed in the IR results, indicating strong nonbonded interaction of the Si-O tetrahedra with asphalt. These changes in Si-O vibrations suggest both distortion in the Si-O tetrahedra and also stronger interactions between asphalt and NC.

The introduction of engineered nano clay to asphalt leads to dramatic changes to the physical behavior and nature of asphalt, which appears to result from molecular interactions between asphalt and nano clay. It appears that addition of engineered nano clay to asphalt has tremendous potential to tailor the properties of asphalt, based on type of application. The current study has been undertaken for a particular type of asphalt and further studies will be needed to include all types of asphalt. Further mechanisms of interaction between nano clay and asphalt are investigated but further studies will be needed to address the low-temperature behavior of the asphalt-nano clay system.

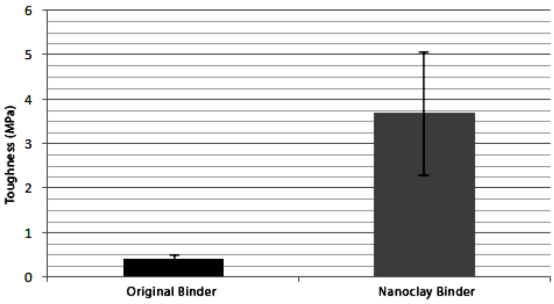


Fig. 7 – Toughness result for original binder and nanoclay modified binders

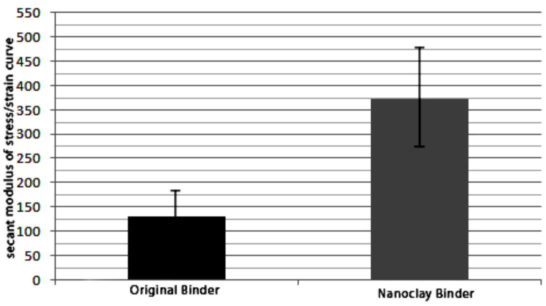
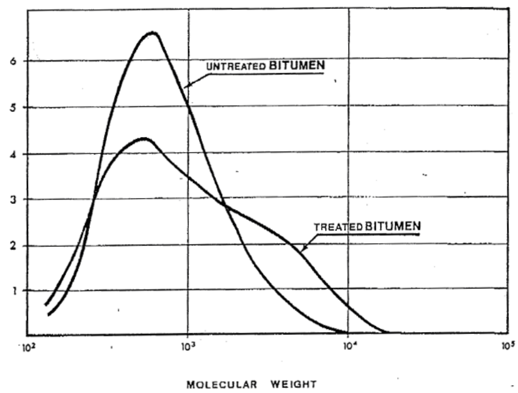


Fig. 8 – Secant modulus result for original and nanoclay



Graph 1 – Molecular weight distribution of Integra Base modified bitumen and unmodified bitumen by High Pressure Liquid Chromatography. Vertical axis represents relative absorbance in arbitrary units and horizontal axis molecular weight

2.4 Nano-Sensors

2.4.1 What is Nano Sensor?

A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument [8]. Nano sensors are same as other sensor but the main difference is that nano sensor dimension are at molecular or atom level. There are different types of nano sensor are following:

- Chemical nano sensor.
- Synthetic nano sensor.
- Organic nano sensor.
- Inorganic nano sensor.
- Bio nano sensor.

2.4.2 How Nano Sensors Improve Road Engineering?

Sensors have been developed and used in construction to monitor and control the environment condition and the materials / structure performance. One advantage of these sensors is their dimension (10^{-9} m to 10^{-5} m). These sensors could be embedded into the structure during the construction process [3]. A low cost piezo ceramic-based multi-functional device has been applied to monitor early age concrete properties such as moisture, temperature, relative humidity and early age strength development. The sensors can also be used to monitor concrete and bitumen road corrosion and cracking. The smart aggregate can also be used for structure health monitoring. The disclosed system can monitor internal stresses, cracks and other physical forces in the structures during the structures life [2, 1]. It is capable of providing an early indication of the health of the structure before a failure of the structure can occur. Some of the sensors can also help to reduce sound and air pollution from road.

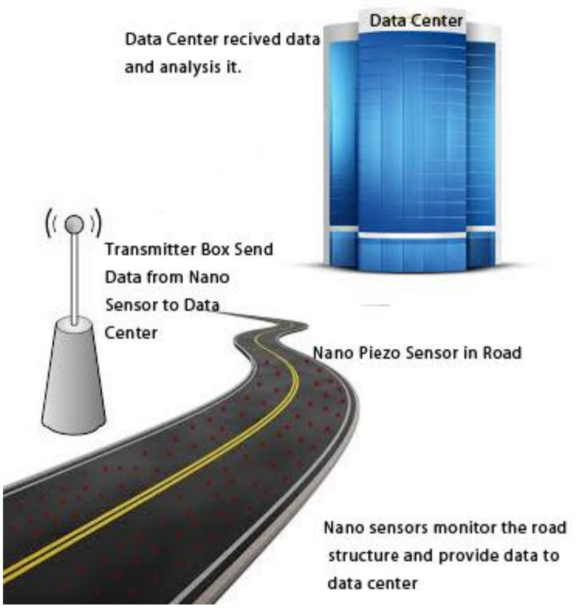


Fig. 6 – Nanosensors monitor the road structure and provide data to data center

3. FUTURE OF NANO ELECTRONICS AND OTHER NANOMATERIALS

The result of the survey and the desk study appear to indicate that nanotechnology R&D having broad area in road engineer. Nanotechnologies are still considering small, fragment pursuit and unknown outside the scientific circle, new technology for road engineering. We study and trace Expenditure on nano technology research is significant, however, the research is continuously moving forward motivated by immediately profitable return generated by high value commercial product. The uses of nanoclay to increase the compatibility of bitumen and polymer / waste plastic / waste tyre research are the future needs to be studied in depth.

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