Applications of Nanotechnology in Road Construction

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Abstract

Nanotechnology is the technique in which nanoscale properties of materials are used in design, construction of the structure. Earlier this technology has been mainly used in field of medicines, biochemistry or microelectronics which work at micro level. Developments in field of nanotechnology have changed our abilities and expectations to change the properties of materials so that they can be used in various fields. Nowadays use of nanotechnology is increasing day by day in the field of Road Construction Engineering. Materials have got some special properties at nanoscale which is used in nanotechnology. Nanoscale properties of materials are used for preparation of nanocomposite which can be used in road construction. The use of nanotechnology lies in the area of modification of existing material properties so that sustainability of material and its durability is increased with provision of users comfort when the material is used in road construction.

1. INTRODUCTION

Material possesses some special properties at nanoscale which are not found at macro scale. In nanotechnology nanoscale properties of materials are utilized. Nanoscale is considered from 1nm to 100 nm. Road construction works are carried out in kilometres and compared to it nanoscale is too small. So a question may come in mind that how these two are correlated. The answer to this is that in nanotechnology nanoscale properties of materials are utilized for improvement in quality of conventional road construction materials. Huge amount of conventional road construction material can be improved by mixing a small amount of nanomaterials. Nanomaterials are used in road construction for providing durability, safety, economy and improvements in other road properties. Nanotechnology uses nanomaterials leading to new cement concrete / bitumen products and materials which are sustainable and reduce environmental pollution.

2. How Nanotechnology Works

The nanoparticles interact with conventional materials and change physical parameters of bulk material dramatically. The nanomaterials possess highly reactive isolated sites which are capable to change electronic of bulk material so physical properties of bulk material gets changed. To develop nanocomposites the fundamental change of physical properties may be understood properly according to which properties of nanocomposites can be modified. The following properties of nanomaterials make it different from macro materials because these do not occur in macro environment.

(i) Interfacial or surface effects
(ii) Effect of scale
(iii) Quantum effect due to changed electronic structure

The above effects are interdependent and they are due to extremely small size of nanoparticles. The first effect depict that nanoparticles are not inert in host material and there is interaction between surrounding material and nanoparticles.

The second statement is related with mean free path. The physical phenomenon in question will exceed the object dimensions i.e. physical phenomenon may jump the process. The third effect is due to fact that nanoparticles are small and they impinge electronic structure of the host material and change the electronic structure of host material. These effects are interrelated and these serve to highlight important issues appearing at nanoscale**.**

3. USE OF NANOTECHNOLOGY IN ROAD CONSTRUCTION

Nanotechnology is a developing research area and novel properties of materials developed with the help of nanotechnology can be used for better road construction. By gaining control at nanoscale excellent results can be obtained. Carbon nanotube is a good example for this. The tensile strength of CNT is 100 times more as compared to that of steel. Nanotechnology can be applied for betterment in road construction e.g. improvement in durability of roads, safety and economy etc. Use of nanotechnology can be done in different fields of road construction. It can also be used in road maintenance works. Use of nanotechnology may lead to faster road construction and improved performance of roads. The road construction work involves mainly the following types of works-

- Cement Concrete Road Works
- Bitumen Road Works
- Steel Works
- Other Miscellaneous Works

3.1 Nanotechnology for Cement Concrete

Cement concrete is an important material for road construction. Now a days cement concrete roads are getting more and more importance. Effects of Chemistry, Physics. Material Science, Civil Engineering etc. can bring change in cement properties using nanotechnology. When small quantity of nanoparticles is uniformly mixed with cement concrete the cement particles deposit on nanoparticles and they accelerate the hydration process of cement(Bijornstrom et al. 2004)[1]. Nanoparticles fill the nanosize pores of cement. When nanoparticles of silica mixed in cement they quickly react with calcium hydroxide of cement generate C-S-H (Sobolev 2005)[2]. Stiffness of cement is improved by C-S-H and it also increases the durability of cement concrete.

Nanomaterials used in cement concrete: Some important nanomaterials which are used in cement concrete are as under-

- **Carbon Nanotubes-** They are nanoscale tube of graphite carbon. They can be single walled (SWNT) or more than one wall (MWNT).
- **Properties-** (i) CNT is highly flexible. (ii) CNT is mechanically strong. (iii) It is the stiffest and strongest fibre.

Adding CNT causes the faster hydration of cement concrete. This creates strong bond between cement concrete and itself. On adding the CNT in cement concrete the compressive strength of concrete increases up to 70% (Marker et al.) [3]. Its addition in cement concrete reduces the thermal conductivity of concrete up to 12% (Yakolov et al)[4]. An important property of CNT is that it does not corrodes in corrosive environment. Its application is especially beneficial in marine environment.

- **Nano silica-** It is much better as compared to silica used in conventional concrete.
- **Properties-** (i) It gives high compressive strength to concrete. (ii) Provides high workability with reduced water cement ratio. (iii) Fills up

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the micro pores and micro spaces in the cement concrete. (iv) Provides cement saving up to 35-40%.

3.2 Bitumen Road Works

Roads are being constructed with the use of bitumen as a binder for a long time. It is possible to improve the qualities of bitumen with the help of nanotechnology. Different nanomaterials can be used for modification of bitumen qualities. Some of them are as under-

3.2.1 Improvement in Bitumen Quality by Nanoclay:

Polymer modifiers used for improvement of mechanical and physical properties of bitumen are costly due to which the construction cost of pavement goes very high. For reducing the road construction cost recently researchers have suggested the use of nanoclay for modification of asphalt quality. Nanoclay is found in abundance in nature so its production cost is very low. For asphalt modification the required quantity of nanoclay is small hence by using nanoclay modification of bitumen properties can be done at low cost. For modification of asphalt quality montmorillonite (MMT) is widely used nanoclay. This nanoclay consists of layered silicate structure having one octahedral alumina sheet sandwiched between two tetrahedral silica sheets. When small amount of nanoclay is used for modification of bitumen quality its physical properties are successfully enhanced. Nanoclay modification in bitumen increases the stiffness of bitumen and the rutting resistance of the bitumen is also improved. Nanoclay modification of bitumen also improves the Marshall Stability and indirect tensile strength of the bitumen concrete.

3.2.2 Improvement of Bitumen Quality by CNM:

Due to poor quality of bitumen pavements made of bitumen break before their due time. Often bitumen does not have proper adhesion quality which is necessary to agglutinate material pieces (aggregates). In winters bitumen fragile due to cold. In temperature fluctuating areas where temperature fluctuation is very high or where winter remains for a long time formation of cavities or pot holes occurs in the asphalt. So improving the quality of bitumen is most essential. For improving the quality of bitumen different nanoparticles like carbon nanotubes, fullerence, nanodiamonds etc. were tried but there performance is poorly investigated (Inozemtcev SS 2010) [5].

A number of scientists tried carbon nanotube modifier for improvement of bitumen quality. CNT was used as a modifier with a amount of 0.005% of bitumen weight and its result was found as increase in strength as well as flexibility of bitumen. These are important qualities of bitumen. In addition to above improvements heat, water and cold resistance of bitumen was improved on addition of carbon nano modifiers in the asphalt concrete (Zaporatckova et al.)[6].In a separate work for modification in asphalt concrete quality carbon nanotubes were used in amount of 0.2% to 10% of the weight of bitumen. The result of using CNT in asphalt concrete gave high wear resistance of asphalt concrete and its durability was also increased (Kondratiev et al.) [7].

3.3 Steel Works

Nanotechnology is also very effective in steel works. The main required properties of steel are its strength, corrosion resistance, ability in welding. It should be economical as well. American Iron and Steel in collaboration with US Navy developed a steel with higher corrosion resistance. The trade name of that steel is Sandviknanoflux which has ultra-high strength. This low cost steel is developed by adding copper nanoparticles and carbon nanotubes in the steel (Zhi et al.) [8].

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3.4 Other Miscellaneous Works

Nanomaterials can be used in various miscellaneous works indirectly relate with road construction. Some of the important applications of nanomaterials are given below.

3.4.1 Photocatalytic Activities of Nanomaterials:

If TiO_2 is mixed in cement concrete it makes cement concrete in such type of material which has ability to perform photo catalytic activities (Casser et al.)[9].This photo catalytic reaction is useful in removal of SO_x, NO_x, NH_3 and CO gases from the atmosphere. The reaction is initiated by ultraviolet rays of atmosphere when they fall on TiO_2 mixed in cement concrete. The TiO_2 in concrete activates photo catalytic degradation of pollutants like SO_x, NO_x, CO and industrial emission (Vallee et al.)[10].The effect of photo catalytic reaction of TiO_2 was found to be much more effective in NO_x removal (Kamitani et al.)[11]. Addition of TiO_2 in road cement concrete will make the road environment friendly.

3.4.2 Nanophosphors:

Illumination of road surface is necessary for road safety and visibility in night. This is especially required in rural areas. Nanophosphors when used with road surfacing materials e.g. cement concrete or paints etc. provide a solution for road illumination problem. Having crystalline structure nanophosphors can have size dependent band gap which creates change of light colour (Kelsall et al. 2004). [12].This way roads constructed with mixing of nanophosphors in construction material can provide light on their surface giving rise to road safety as the light source will not be external. In researches it has been developed that nanophosphors can be mixed with concrete, bitumen which are used for road construction or they can also be mixed with road paints. On mixing of nanophosphors these materials become luminescent on exposure to light (Steyn et al. 2007) [13].

3.4.3 Nanomaterials for Surface Runoff:

Road surface become hydrophobic on application of nano size ZnO_2 on road surface. This hydrophobic road surface leads to quicker run off from the rete of roads. Self –diagnostic ability for stresses can be developed in cement concrete by addition of nanoFe_2O_3 in cement concrete. In addition nanoFe_2O_3 improves compressive and flexural strength of the cement concrete (Li et al 2004) [14].

3.4.4 Nanotechnology for Reducing Permeability of Cement Concrete:

On addition of nanoSiO_2 permeability of cement concrete should decrease with increase in service life of concrete as well as its durability (Sobolev et al.)[15]. Water permeability test performed after addition of nanoSiO_2 in cement concrete gave lower permeability as compared to the normal cement concrete(Tao Ji 2005)[16]. After cationic exchange nano organo-mont-morillonite (OMMT) becomes hydrophobic and they can be used to reduce the permeability with increase in the strength of the cement concrete. On mixing of optimal dosage of OMMT nanoparticles in cement concrete coefficient of permeability gets down up to 100 times.

3.4.5 Nanotechnology for Improvement of Workability:

Segregation resistance of self-compacting concrete was improved by the addition of amorphous nanosilica (Bigley and Greenwood 2003) [17]. On addition of nanosilica particles in concrete it was found that it developed high performance and self- compacting concrete. Workability and strength of concrete is also improved by addition of nanosilica. Nanoclay can be used for producing self- compacting concrete which can be used in slip form paving. In slip form paving material must be stiff enough with proper

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workability so that it may stand without form work when paver moves away after paving.

3.4.6 Abrasion Resistance:

Wearing away by friction is called abrasion. Nanomaterials like SiO_2 and TiO_2 on addition in cement mortar increased abrasion resistance up to 90 to 180 percent. The abrasion resistance of cement concrete having nanomaterials SiO_2 and TiO_2 was studied by (H. Li et al 2006) [18]. It was found that abrasion resistance of concrete in which nanoTiO_2 was mixed was better than that concrete in which same amount of nanoSiO_2 was mixed. Effectiveness of nanoTiO_2 in abrasion resistance is maximum when 1% of nanoTiO_2 is mixed in cement concrete.

3.4.7 Flexural fatigue:

Nanoparticles can improve the flexural fatigue performance of the cement concrete and addition of nanoparticles also improves the sensing property of their flexural fatigue. A cement concrete mix in which 1% nanoTiO_2 has been added showed best flexural fatigue resistance even it was found better than when polypropylene fibres is mixed in cement concrete. TiO_2 mixed cement concrete has been extensively used for making pavements (Li et al 2007) [19].

3.4.8 Nanotechnology for Roads in Water Logging Areas:

Nanotechnology can be used for road construction in water logging areas. It is used for making the soil water proof which increased CBR value under wet condition. It is also useful in stopping the capillary rise of water. Additional benefits obtained are increased life span of road and nearly negligible maintenance cost. Saline is a nano semi solid white paste. It is soluble in water. Application of water soluble saline creates a water proof soil layer between flexible pavement and natural soil. In this method saline of size 50nm and acrylic copolymer of size 100nm are used. By using this method life of road increases minimum for 1 to 3 years. In a practical design (Jay et al.) [20] were able to reduce the thickness of flexible pavement from 710mm to 600mm using CBR method of design. The CBR value of the wet soil increased considerably on use of saline treatment.. It is good for construction of roads in water logging areas.

3.4.9 Protection from Environmental Effects:

By protecting the infrastructure from environmental effects general life of the infrastructure can be increased. For protecting the road infrastructure from environmental effects different types of nanocomposite coatings are available. These coatings can be applied on concrete surface. These coatings make better bond with substrate material providing robust layer for environmental protection. These coatings utilize nano scale properties of the materials.

3.4.10 Bond Improvement by SAM:

Self assembled monolayer film is called SAM. This is a film of nano size material which is deposited on the aggregate material by various techniques. The object of such treatment is changing the surface properties of host materials. Its main aim is to improve bond between the aggregate and the binder (e.g. cement or bitumen). Adhesion between aggregate and asphalt is improved by the SAM. Benefits of SAM on concrete were noticed by Sanfilippo and Munoz (2009) [21] in form of enhanced mechanical properties of concrete and stopping of harmful reaction between aggregate and cement.

4. REASONS FOR APPLICATION OF NANOTECHNOLOGY IN ROAD CONSTRUCTION ENGINEERING

Nanotechnology is not only implemented in the field of road construction engineering because it

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is a new technology but it is applied in road construction engineering because it can solve those problems which cannot be solved using present macroscale technologies. To use nanotechnology in road construction initially those areas are identified where nanotechnology and road construction engineering can complement each other. The challenges are examined in consideration of properties of nanomaterials. Impact of nanotechnology on life style of society is also think about. For obtaining sustainable pavement (Maher et al. 2006)[22] gave following criteria-

(i) Minimizing the use of natural resources.
(ii) Reduction of energy consumption.
(iii) Reducing greenhouse emission.
(iv) Limiting the pollution.

To obtain the above qualities in road pavement it is important to have knowledge of those problems which cannot be solved by the current technology and then consider their solutions through nanotechnology. The nanotechnology solution must have potential benefit and it should be considerable with its cost effect. In this way nanotechnology benefits can be obtained by developing improved materials and specifying the uses of novel materials.

6. CONCLUSIONS

Nanotechnology is new area for research work in the field of road construction engineering. Here novel properties of nanomaterials are used for construction of roads. Numbers of nanoroad materials exist which are capable of changing the service life and whole life cost of the road. Nanotechnology is capable of solving many engineering problems related with road construction. Even nanotechnology applications can lead to advance problem solving techniques in road construction. In road construction engineering nanotechnology can give low cost solutions for typical problems. Fundamental research for improving the properties of existing construction materials is an important output of nanotechnology. Nanotechnology improves the quality of structural materials in two ways. In the first way they improve the strength of already existing materials such as bitumen, concrete, steel etc. It is done by making nanocomposite materials by adding nanomaterials in bulk materials. In other ways nanoparticles can improve other road qualities such as photo catalytic works for improvement of environmental pollution, nanophosphors for providing luminescence on road surface / providing brightness in paints. There are nanomaterials which can improve bond, abrasion resistance and decrease permeability of cement concrete. Thus nanomaterials are bringing many fold improvements in road construction technology.

7. RECOMMENDATIONS

(i) For application of nanotechnology in the field of road construction easy methods should be developed by the working engineers so that public may get aware of the benefits of it.

(ii) New researches should be continued by the scientists in the field of nanotechnology so that road construction engineering can be benefitted by the nanotechnology.

(iii) Gap between scientific inventions and field applications of nanotechnology may be minimized or removed.

(iv) For getting better solutions to the problems in road construction nanomaterials may be used as far as possible so that society may be benefitted by the nanotechnology.

(v) Impact on environment around the constructed road with nanomaterials may be watched very carefully so that they may not cause any harm to the environment.

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(vi) Public may be made aware about the economic benefits and durability of the nano road materials.

(vii) Problem solving benefits of nano materials in any specific area may be made common among the public.

Based on the above it will be wise step to continue focused and useful researches in the field of Nanotechnology so as to construct long life and economical roads for public use. Benefits of Nanotechnology in road maintenance works may also be taken to obtain easy and durable maintenance of the roads.

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