Potential applications of nanotechnology in maritime environment

Nanotechnology is poised to revolutionize the fields of materials science, physics, mechanical engineering, bioengineering, chemical engineering and most of the other fields of technology. It is thus imperative that this technology will have many potential applications in the maritime environment. The very fact that any ship is a self sustained entity in respect of all walks of life makes it prudent that no part of the ship will be untouched by application of nanotechnology. Most of these applications are in the conception/infancy stage and therefore are referred to as potential applications. The potential applications of nanotechnology in various aspects of the marine environment are discussed in this chapter. The key guiding criterion analysed for each broad area of application are:-

(a) Does application of nanotechnology give distinct advantage over the existing technologies for the desired purpose?

(b) Is the application of nanotechnology feasible for the desired purpose or is it like a fictional concept?

(c) Is the application of nanotechnology for the desired purpose economically viable?

Structural Applications

2. Any marine vessel which is intended for any function ranging from weapon carrying platform, cargo carrier to research vessel has to have sea worthy structure. Nanotechnology promises numerous modified material which can give phenomenal strength advantage by nanostructuring the materials. This is practically achieved with the help of composites. The various potential

applications of nanotechnology in composites for naval applications are discussed in following paragraphs.

3. Nano Aluminium Composite. It has been found by researchers in United states that by usage of advanced nanoscience in the processing of aluminium results in superior material for tough and lightweight structural applications. This process is known as cryomilling and it involves introducing nano aluminium in the standard aluminium. This process leads to the formation of nanoscale aluminium oxide and nitride particles, which makes the material stronger and stabilizes the microscopic orientation and structure. The tests conducted on the yield and tensile strength have shown improvements of 150 percent in strength over untreated aluminium. This nano-treated aluminium can be an extremely efficient substitute for making aluminium hulls, aluminium superstructures and various other ship structures where light weight and high strength are highly desirable.[1]

4. Clay Nanoparticles. These are composed of several aluminosilicates and are called as nanoflakes. These, when incorporated in composites, can incorporate flame retardance, anti-ultraviolet and anti-corrosive behaviour. As a quantitative measure, an addition of 5% of the mass fraction of these nanoparticles in composite fibres shows an increase by 40% in tensile strength and 60% higher flexural strength as against their conventional counterparts. These composites can be used for making sturdier sails, composite structures, boat hulls and even as additives for paints.

5. Metal Oxide Nanoparticles. These are nanosize particles of TiO_2, Al_2O_3, ZnO and MgO. These nanosized metal oxides when added to fibres and paint

coatings have shown to increase the antimicrobial, ultraviolet blocking function and self-decontaminating function as against their conventional counterparts. These metal oxide additives can be used for making better fibres and coatings. sturdier sails, composite structures, boat hulls and even as additives for paints.[2]

6. Carbon Nanotubes. This is one of the most talked about material with nanostructured base. It is one sixth the weight of steel with 100 times the strength and excellent thermal conductivity comparable to purest diamond and thermal conductivity similar to copper. These can be impregnated into polymers for explosion proof structures, safety harness and electromagnetic shielding. These can be used for various riggings and load bearing applications.[3]

7. Nanocellular Foam Structure. This structure is made by introducing certain amount of nanoporosity in material which results in lightweight, good thermal insulation and high cracking resistance with no compromise in the mechanical strength. This aspect can be utilised in providing superior insulation materials which are extensively used in the outfitting of the ship structures.

8. Analysis. The application of nanotechnology in composites as discussed above promises increased strength for lower weight which is an ideal situation for weight sensitive marine applications. Any weight saved can be translated into usable payload or cargo carrying capacity depending on the end use of the ship/vessel. It is therefore inferred that the structural

nanocomposites have potential application in maritime applications view following:-

(a) The quantum of tangible benefits achieved using nanotechnology based structural composites cannot be achieved by existing micro based structural composites.

(b) The composites are achievable and have been manufactured as part of research/ in situ testing.

(c) The cost benefit analysis is not very clear at this stage. However, with the success of research/tests and the results like 100 times increase in strength as in case of carbon nanotubes, it is a realistic estimate that in future these applications will become cost effective.

Application of Nanotechnology for Protective Coatings

9. Marine environment is one of the harshest any structure could be subjected to in the lifecycle. Corrosion therefore becomes a necessary evil for all marine structures and poses a daunting challenge. It is therefore imperative that extensive research and development goes into ever improved protective coatings for marine structures. Nanotechnology promises a new era in protective coating that is named nanocoating. These are coatings that are produced by usage of at least one component at nanoscale to obtain desired properties. The most recently reported potential application of nanotechnology for improved protective coatings for marine structures are discussed in following paragraphs.

Wear rate for traditional zirconia (A) coating v/s nano zirconia coating(B)

10. Scratch Resistance. The paint coatings are added with scratch resistant additives to improve scratch and abrasion resistance and maintain an attractive appearance over long periods of time. Nano-sized (< 50 nm) inorganic particles have been observed to provide much better wear and scratch resistance when compared to same material at microscale. Further, nanoparticles due to their small particle size, do not effect the transparency of clear coats. The wear rate for (A) traditional zirconia coating v/s (B) nanostructured zirconia coating are shown in figure. It is clearly seen that the performance of nanostructured coating is much superior[4].

Colour change with time in QUV weatherometer for organic UV filter, nano ZnO20 and nano ZnO805.

11. Ultra Violet Resistant Coatings. The photochemical degradation caused by ultra violet(UV) rays is common mode of failure of most of the coating systems. This causes the oxidation and decomposition of polymer films along with inorganic or organic pigments which leads to discoloration and cracking of paint films. Using nano particles like titania or zinc oxide (ZnO) have shown improved UV resistance in the coatings. The experimental results of high UV opacity of the nanoparticle form of zinc oxides against conventional zinc oxide in the coating applications is shown in the figure. It is clearly seen that the nano ZnO addition leads to significantly less yellowing.[5]

Photographs of water and oil droplets on nano particle coated panel.

12. Water and Oil Repellent Coatings. The addition of nano particles to coating systems increases the surface area and pore volume, which in turn increases the surface roughness of a surface. This has been observed to make the surface as water and oil repellant. Water and oil repellent surfaces can be exploited for self cleaning mirrors, building exteriors, domes and ships. It has been reported that addition of titanium oxide nanoparticles in the polymer coatings results in water and oil repellent coatings. The photograph of water and oil droplets on nanoparticle modified coating is shown in the figure and is clear that the water and oil droplets are unable to wet the coated surface.[6]

13. Lotus Effect. Another interesting application of the nanoparticle addition in paint coatings is the self cleaning of surface using ' Lotus Effect'. In the lotus effect, oxidation and chalking of the paint film is limited to the very near surface layers such that over time, rain water will wash the top layer leaving an underlying clean fresh surface. This development of self cleaning paint surfaces can be a boon for exteriors of tall buildings, structures and ships, which will clean on their own and will require minimum maintenance. [7]

14. Fire Retardant Coatings. Recent research into the application of nano-size particulate on flame-retardant coating has demonstrated that nano-fillers can improve fire retardancy of the paint films. It has been observed that the flame spread rate reduces with increase in weight percentage of nanocomposites as shown in the table below. This leads to fire redundancy

for the coating with increased reaction time for fire fighting. These coatings can be a major development in the fire safety for the coatings applied inside the ship compartments.[8]

Flame spread rate with increase in weight percentage of nanocomposites

15. Improved Anti Corrosive Coatings. The nanoparticles because of their greater surface area can absorb more resins compare to conventional pigments. This reduces the free space between the pigment and the resin. Thus, nanoparticles increase the density of coating, reduce the transport path of corrosive species and enhance the protective performance. A comparison of the anticorrosive properties of coating with optimum level of nanoparticles show far better results than a conventional coating.[9]

16. Anti-Bacterial Effect. Avoiding infection from surface contact is vital in specific environments like onboard ships in the galleys and sickbays. Experimental results show that the ability of the nanoparticles to destroy bacteria is better than the conventional microparticles . This aspect is being researched to provide a coating that is hygienic and destroys any contaminants like bacteria on the surface.

17. Anti Fouling. A team of researchers at the Hanover School of Veterinary Medicine in Germany have discovered that whale’s skin has a specialised nano-structure that stops the build-up of microscopic organisms such as barnacle larvae. They plan to mimic the idea in anti-fouling paints with provision of nanoridges in polymer matrix to give effect similar to whale’s skin. This can potentially remove the requirement of anti fouling paints.[10]

18. Nano Ceramic Coating for Underwater Valves in Submarines. The ball valves that regulate water flow in submarines during diving and surfacing, suffer from metal-on-metal friction and resultant corrosion. Repair by replacement results in costly and time intensive procedures such as pressure hull cutting. This leads to submarine being out of operational availability for extended durations. The solution of the problem has been attempted using aluminum-enhanced nano ceramic coating. The results are encouraging and the preliminary results show that the ball valves may last the life of the submarine.

19. Smart Coatings. These coatings as the name suggests are not smart in themselves and they have no built in intelligence as is possible when designing active smart systems. These are passive structured coating systems that provide a desired pre-determined response to a external stimulus. They react to outside conditions, such as temperature, stress, strain or the environment, in a selective way. With the advent of nano-technology in smart coatings , it is possible to have coatings which can predict onset of corrosion, can release healing agents to cure coating cracks and allow protective coatings to release corrosion inhibitors on demand to name a few applications. Future development of protective coatings will take advantage of this aspect of coating technology and are likely to be the coatings of 21st century.

20. Analysis. The application of nanotechnology in protective coatings as discussed above promises improved scratch resistance, corrosion resistance, ultra violet resistance and some novel concepts such as fire retardant coatings, self cleaning coatings, nano based anti fouling coatings and smart

coatings. These enhanced properties and potential novel concepts can bring paradigm shift in the way coatings function. It is therefore inferred that the application of nanotechnology in protective coatings have potential application in maritime applications view following:-

(a) The quantum of tangible benefits achieved using nanotechnology in protective coatings cannot be achieved by existing protective coatings.

(b) The coatings are achievable and have been manufactured as part of research/ in situ testing.

(c) The cost benefit analysis at this stage is not favourable, however, with improvements in the manufacturing processes and the benefits accrued by novel concepts like self cleaning coatings, fire retardant coatings, these coatings will become a potent feasible solution in near future.

Nanotechnology in Stealth for Marine Applications.

21. Stealth. The application of stealth technology in warship construction to reduce radar cross section, magnetic signature and infrared signature has been the ongoing endeavor of the ship designers. The advent of nanotechnology has given new concepts in the field of stealth technology. The significant nanotechnology based stealth applications for warships are discussed in following paragraphs.

22. Adaptive Camouflage. Adaptive camouflage is a concept where the material surface changes external appearance in response to a preprogrammed stimulus in the environment in which it works. In order to achieve adaptive camouflage the material surface is cover with thin plastic

sheets. These sheets have numerous embedded light-emitting diodes (LEDs). The colours and patterns displayed on the sheet are controlled by the LEDs with inputs from a camera which scans the surroundings. This adaptive change of colour and pattern can be used as a effective deception tool in tactical situations. Several nanotechnology enabled techniques are in research and development stage and can be applied for adaptive camouflage. The two major variants of the adaptive camouflage are as follows:-

(a) Active Systems. These systems use lighting techniques, mainly based on miniaturised LED-technologies . These systems have a coating of fibers which are attached to super bright LEDs. These LEDs can emit any colour which is directed by microchip through a battery power source. The fibers are originally colorless but their colour can be manipulated by controlling the emitted power by the LEDs. If a optical sensor is attached then it is possible to change the colour of fibres as per the colours of the surrounding. This can be a like a real time camouflage and can effectively be utilized as a revolutionary stealth feature in the warships.

(b) Passive Systems. These systems use tunable photonic crystals. At the University of California, Riverside, nanotechnologists have succeeded in controlling the color of very small, nanosized particles of iron oxide (photonic crystals) simply by applying an external magnetic field to the solution. The discovery has potential to control the external appearance based on a passive external stimulus. Iron oxide crystals are the first examples of photonic crystals that is fully tunable in the visible range of the electromagnetic spectrum, from violet light to red light.[11]

23. Propeller Coating for Minesweepers. The minesweepers have to avoid magnetic materials to make them immune to magnetic underwater mines. The propeller shafts are purposely made from bronze to suppress the magnetic signature, Bronze is softer than steel and susceptible to frictional wearing in the operating environment. Replacing these shafts requires dry-docking which adversely affects the operational availability of the ships. The nano enhanced ceramics have been used on experimental basis on these bronze shafts. The preliminary results indicate that the coating is unaffected by highly erosive shaft operating conditions. This can be a highly effective solution of the erosion corrosion in the shafts of minesweepers without compromising the magnetic signature of the ship.[12]

24. Analysis. The application of nanotechnology in stealth as discussed above promises a distinct jump in the concept of stealth It is therefore inferred, that the application of nanotechnology in stealth have potential in maritime applications view following:-

(a) The concepts such as adaptive camouflage achieved using nanotechnology are not feasible using the current micro based technologies.

(b) The concepts have been achieved in the ongoing research and development efforts.

(c) The cost benefit analysis in not applicable as the stealth features achieved are not achievable by the existing concepts.

Nanotechnology in Marine Electrical Applications

25. Artificial Intelligence. Artificial intelligence simply means the use of computer to in order to think, reason, communicate and create things along the lines of human brain. Machines can communicate and share data in a much more efficient and flawless manner than the human brain. Biological human thinking is limited to 1016 calculations per second (cps) per human brain (based on neuromorphic modeling of brain regions) and about 10 26 cps for all human brains. It is expected that the application of nanorobots could help enhance the 100 trillion very slow interneuronal connections with highspeed virtual connections. With the advent of nanotechnology the processing capability of non-biological intelligence or strong artificial intelligence is likely to exceed biological intelligence by the mid-2040s. This will open up vast applications like nanorobots manning unmanned vehicles, paradigm shift in decision making of automated controls and may be the use of virtual crew to man automated ships.[13]

26. Nano Battery System. The availability of uninterruptible power supply (UPS) on naval ships is a vital requirement. In order to ensure UPS two generators are kept online to ensure uninterrupted power supply Research is being taken in United States to design a large-scale nano lithium titanate military battery system. In case the primary generator fails, this nano battery system is envisaged to provide UPS till secondary generator comes online. This will enable ships to run only one primary generator . The fuel cost savings are expected to be nearly $1 million per vessel for a six month cruise.[14]

27. All Electric Ship. The naval researchers in United States are working on the feasibility of design and construction of an all-electric ship. It is envisaged that the application of nanotechnology will miniaturise the bulky systems in use as on date. These miniaturised systems will occupy lesser space and with abundant electricity available, it may be feasible to develop an all electric ship. As there will be large amount of power available the feasibility of developing a electric rail gun-which, is one of the Navy's weapon of the future is also being researched.[15]

28. Inefficient IC Design at Nanoscale. The design of integrated circuits (IC) faces a big challenge in terms of efficiency of the transistors. This leads to issues such as problems of timing closure, eliminate global clocks and tolerate parametric variation. It has emerged that usage of nanotechnology may lead to usage of numerous available transistors and logic devices so that using each one with maximum efficiency will no longer be a binding consideration. This may be possible with IC design at 45 nanometers and below. These IC will have some area inefficiency and lower gate utilization, however power and performance targets will be met much more efficiently than the conventional IC as larger number of ICs can be fitted in smaller area.

29. Asynchronous Circuits at Nanoscale. The use of asynchronous architectures in IC design removes the problem of timing closure, eliminate global clocks and tolerate parametric variation. However these circuits are two to six times the area of synchronous circuits. However, at nanoscale, these asynchronous circuits can be produced at significantly reduced areas. This application of nanotechnology will make asynchronous circuits a viable

option at 65 nm and below. These circuits will be a more reliable solution for critical applications such as fire contol systems. .[16]

30. Analysis. The application of nanotechnology as discussed above mainly discusses concepts which are futuristic and will be a major advancement in the way systems are operated and controlled with present technologies. It is therefore inferred that the application of nanotechnology in artificial intelligence, IC design and power back up systems have potential in maritime applications view following:-

(a) The concepts such as inefficient IC design, asynchronous IC design, UPS for ships and artificial intelligence to control ships are not feasible using the current micro based technologies.

(b) The concepts are at inception/design board stage of the ongoing research and development efforts.

(c) The cost benefit analysis can be undertaken when the concepts become reality from the design boards. However, the advantages outweigh the cost criterion and efforts must be sustained for researching applications in these areas.

Nanotechnology for Warfare Concepts

31. Under Water Warfare. Research is vigorously on to improve future anti submarine warfare/ mine warfare capabilities through the use of nanotechnology. The ability to develop nano based micro-sensors that could be scattered on the ocean floor to detect enemy submarines could lead to a paradigm shift in the Navy’s undersea warfare systems and capabilities. The

same concept can be tailored for detecting enemy mines in the littorals. These furturistic nano based sensors will be networked and can be laid/controlled from distant locations.

32. Research for Combat Outfits. A significant amount of research is directed at use of nanotechnology for ‘ lightening the load’ of soldier/sailor in combat. One can expect that nanotechnology based soldier-worn systems will be introduced in the near future. In 2002, the Institute for Soldier Nanotechnology (ISN) was created at the Massachusetts Institute of Technology (MIT), with a five-year grant of $50 million from the US Army. The aim of the research is focused on revolutionary advances in nanotechnology focusing on the following aspects:-

(a) Greatly enhance the protection and survival of the soldiers.

(b) Real time monitoring of the vital health parameters through the combat outfit.

(c) Improvement in the agility and recuperation from injuries.

(d) Nanofibers for filtration and chemically protected membranes for increased NBC protection.

(e) Nanolayered materials for smart/interactive textiles to help track soldier’s performance .

(f) New lightweight transparent armor for ballistic protection, directed energy (eye)protection, and environmental protection.[17]

33. Nanotechnology for Combat Safe Insensitive Munitions. The Navy's perspective of developing munitions is much more cautious primarily because the personnel and the munitions coexist on ships. There is a unending quest to develop more powerful and effective energetic systems. However, it is to be ensured at all times that these system do not operate accidentally or on false alarm. Nano-based materials can contribute to revolutionary improvements in energetic materials including a paradigm shift in insensitive munitions built around the idea of " Combat Safe" Insensitive Munitions. Nanostructured materials will play a significant role in developing these new class of energetic materials with controlled and tailored energy release. Nano-based energetics is predicted to be a key enabler of advances in military systems in the next 30 year.[18]

34. Viable Fuel Cells Using Nanotechnology. The fuel cells are based on the electrochemical principle of formation of water vapor by reaction of hydrogen fuel and oxygen. These cells are expensive to produce and the platinum/ruthenium alloy catalyst used for the anode in traditional proton exchange membrane (PEM) fuel cells gets fouled by exposure to even trace levels of carbon mono-oxide(CO). This leads to even the best designed fuel cells to fail prematurely. This has prevented the viability and commercialization of fuel cells

35. A research team in Cornell University's Energy Materials Center has fabricated a nanotechnology-based catalyst which is less expensive and more carbon mono-oxide tolerant than the material used in conventional PEM fuel cells. The application of nanotechnology has the potential to decrease the weight of electrodes as well as to increase the conductivity and

electrochemically active surface of catalysts. The mechanical properties, conductivity and corrosion resistance of interconnect and bipolar plates could also be improved with nanocoatings. These properties are predicted to ensure commercial availability of fuel cells in near future.[19]

36. Analysis. This application of nanotechnology to yield fuel cells is likely to make hydrogen fuel cells a commercial viability in near future.[20]These fuel cells can be used for air independent prolusion of submarines. Further, view miniaturization using nanotechnology these cells could help save phenomenal spaces in submarines by replacing the voluminous diesel electric/ nuclear propulsions being used presently. It is therefore inferred that the application of nanotechnology in fuel cells have potential application in maritime applications view following:-

(a) This application of nanotechnology to yield fuel cells is likely to make compact hydrogen fuel cells a commercial viability in near future. The fuel cells using the current technology are heavier and not commercially viable.

(b) The application has been attempted in research and the results are encouraging. Further nano based fuel cells will be compact giving them distinct advantage for applications in air independent applications for submarines.

(c) The cost implications of the current fuel cells is a major hurdle in the commecialisation of the fuel cells.

Nanotechnology in Novel Marine Applications

37. Self Healing of Materials. The biggest challenge in materials science is to design “ smart” materials that can sense the presence of a defect and actively re-establish the continuity and integrity of the damaged area. Such materials would significantly extend the lifetime and reduce breakdowns of manufactured items. Nanotechnology has potential to design a system that could recognize the appearance of a nanoscopic crack or fissure and then could direct agents of repair specifically to that site. The ability of nanotechnology to tailor the surface chemistry of nanoparticles aids in designing self-healing materials. The two recent computational studies on self-healing of materials which can be of immense use in marine applications are as follows[21]:-

(a) In a recent study involving nanoscopic polymer gel particles a coating has been designed that undergoes structural rearrangement in response to mechanical stress, and thereby prevents the catastrophic failure of the material.

(b) In another recent study, the healing agents are encapsulated solid nanoparticles that can deliver the encapsulated nanoparticles to specific cracks on the substrate. Once the healing nanoparticles are deposited on the desired sites, the fluid-driven capsules move further. This strategy is called “ repair-and-go” and has negligible impact on the precision of the non-defective regions and involves minimal amounts of the repair materials.

38. Fossil Fuel Security. The research is on for alternative fuels on ships, modifications of systems using nanotechnology, to put hybrid drives which

can generate electricity from the power going to propellers. It is being predicted that future advancements and breakthroughs in nano technology like all electric ships will help reduce the Navy’s dependence on fossil fuels. [22]

39. Nanorobots for Oil/Water Testing. The current practice of oil and water testing onboard ships is using samples which are time-consuming and has disadvantage that the contaminants not included in the sampling get missed out.. Researchers at the University of Southern California are working on developing technology to build nanorobots which will be able to monitor oil/water for contaminants. The sensors in nanorobots will be able to communicate with one another and will be active so that they can move around and make decisions.[Share this: Facebook Twitter Reddit LinkedIn WhatsApp