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Nanomaterial-Based Energy Storage And Supply System In Aircraft

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Abstract

The expanding aviation industry is now becoming a crucial role in increasing carbon footprints on earth and the day by day competition of lowering the flight fare is at the cost of severe climatic change This paper concludes that using nanotechnology or Nanocomposite in aviation gives the High Strength, Light Weight, Corrosion Resistant, materials with high toughness and durability. Also these materials needs least maintenance and they are reusable. Cheaper and safer coating for the surface of the aircraft is easy with them.

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Keywords: Nano-Structure; Nano-Science; Nano-materials; Composite material; Nano-composite material; Nanoscience; Nanoelectronics;

Introduction

The aviation industry is among one of the most foremost massive trade in the world. Many companies rely on the expertise to transport products and people all around the world faster, and which can only be achieved by air transportation. Along with this huge economic value, however, comes enormous consumption, and one of the largest carbon footprints on the earth relative to the size of the market. A remarkable interest in nanomaterial for the aerospace or aviation sector is justified by the potentiality of nanotechnology and nanoengineering to help the trade to achieve this goal. Nanotechnologies may impart vital improvement in the development of renewable energy sources as well as conventional sources of energy. Nano-coated, storage device allows the optimization of lifecycles and efficiency of systems in the build out of fuel storage tank, hence the saving of costs.
For worldwide transportation of people in shortest time and least hazard, the only means is air plane. For business purpose too, lot of companies are extremely dependent on the performance of airplane. So the proper designing of

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the airplane is required to achieve maximum efficiency and performance. The efficiency can be increased by exploiting the excellent properties of the nanomaterials. Nanomaterials are cornerstones of Nanotechnology and Nanoscience. In recent years there is a tremendous research progress in the field of aviation. Nanoscience has the potential to revolutionaries the aerospace industry[9] as it has offered lots of new materials with diversified functionalities. Many astonishing characteristics of the nanomaterials have made it possible to commercialize many products which have changed the old concepts significantly.

Basically nanoparticles are those which have at least one dimension with 100 nm where 1 nanometer (nm) = 10-9 m. Not all the systems of airplane can be revolutionalized by nanotechnology in recent trend, but surely this new technology can be exploited to some extent to have better system than before. This chapter deals with the possibilities of inclusion of nanomaterials in certain parts including navigation system. For modern aviation nanotechnology has a big prospective either in terms of enabling huge scale energy production process or designing efficient nanocoated energy storage material. But extensive application is still hindered by the shortcomings like isolation of nanoparticles, improved synthesis procedure and critical application.

1.1. Simple Definition Of Nanotechnology

Nanotechnology is the name of the application technology where nanoscience is applied in practical devices. Nanotechnology starts from atoms and molecules and their integration and manipulation to form device. Tailoring of the properties of the materials in the nano range is possible now with nanotechnology especially for commercial and industrial applications. As material properties can be tailored in nanoscience and the devices made from materials, hence it can be said that the whole aviation industry depends on nanotechnology.

Two types of nanomaterials can be defined

1. Non-intentionally-made nanomaterials[3]: This type of nanomaterials are produced during volcanic eruptions, proteins, viruses, etc. or that produced due to unintentional human activity such as diesel combustion.
2. Intentionally-made nanomaterials[3]: Deliberately produced nanomaterials that are produced through a definite fabrication process or the nanomaterials that are produced through some biological activity
   Some good examples are:

- Our nails increase in length of 1 nm in 1 second.
- The tip of a pin is about 1,000,000 nm in diameter
- The diameter of our hair is 80,000 nm.
- A DNA molecule is 1–2 nm wide.

2. Literature Survey

Because of the various useful utilization of SWCNTs in several fields of science, the spectrum of literature published previously related to SWCNTs has been reviewed by me. SWCNTs having many properties in terms of their structure of the atom as well as arrangement, processing method, mechanics, characterization and physical and chemical characteristics in many journals and review papers. This paper has a short overview is mentioned related to properties of SWCNTs and their application in Casing of Jet engine and or Diesel Engine.

- John. H. Lehman et al.[17] reviewed the characteristics of MWCNT. The characterization of MWCNT was effectively done using Raman spectroscopy optical characterization. In Raman spectroscopy, the information regarding the defects, the alignment of tubes and the purity can be estimated to differentiate MWCNT from another type of Carbon allotropes.
- L. Palaniappan et al.[18] focused on the recent progress in the field of CNT research in connection to surface modification, control synthesis, functionalization, and sensor[4] development. He reported that the surface area enlargement and the control of morphology are the key features which influence the performance of the device.

- Elisabetta Cominiet et al.[16] reported that 1-D metal oxides nanowires are optimistic materials in the formation of nanodevices. Tin, Zinc, and Indium oxides formed in single crystalline nanowires by the condensation from vapor phase are reported.
- L.Valentini et al.[14] developed CNT based film by using plasma-enhanced CVD capable of detecting low-concentration of oxidizing gas. The electrical properties of the sensor film were tuned using heat treatments and a transformation from semiconductor to metallic behaviour took place at high temperature.
- R. Cheung et al.[15] prepared Carbon nanotubes uniform using CVD technique. A high yield of CNT was developed on a Si substrate using Ni as a catalyst. The diameter of the Carbon nanotubes was dependent on the annealing temperature, hence the diameter could be controlled based on the annealing temperature before growth.

3. Why Nanomaterials?

Anywhere within the airplane nanomaterials may be used. Nanomaterials in different forms like Nanoceramics, nanocomposites or polymeric nanoparticles Nanomaterials can be used as required in the airplane system.

3.1. Properties Of Nano-Materials

The structure of nanomaterials is in between the bulk materials and those of atoms. The properties of micro structured materials mostly resemble with that of the bulk materials. But nanostructured materials have properties that are significantly different from bulk materials. Such difference of properties[of the nanomaterials is due to the facts

- The nano sized materials have large number of surface atoms
- Their surface energy is very high
- Occurrence of spatial confinement
- Reduced or no imperfection in the nano material

As the dimension of the material reduces to nano range, the surface to volume ratio of the material is increased which leads to a large number of atoms available on the surface. That in turn, increases the possibility of the material to interact with other atoms or group of atoms so that the surface related properties are enhance considerably. Especially if the sizes of Nanomaterials will be comparing to the length of the structure, the surface properties of Nano-materials affects the entire material. Figure 1 and 2 [12] represent the change of properties of a material when its dimension changes from nano to macro.

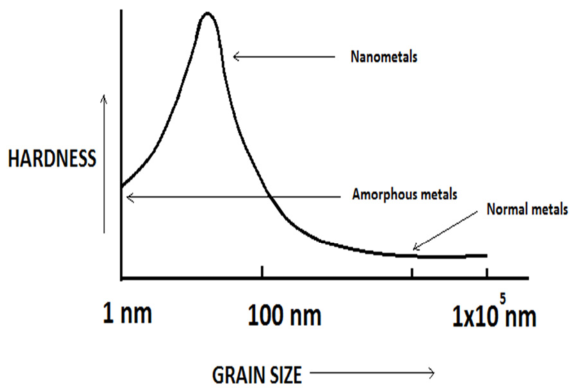

Fig: 1. Grain size Vs Hardness graph
(Reproduced according to reference 12)

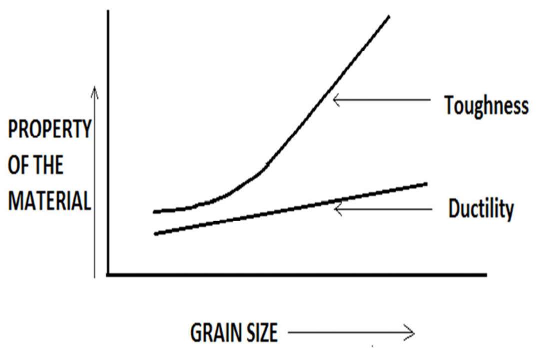

Fig: 2. Grain Size Vs ductility and toughness curve
(Reproduced according to reference 12)

However, when a material is strengthened, the limit is controlled by the size of the dislocation. When dimension reaches 10 nm, the grain boundaries begin to slide. With the increase of strength, ductility decreases for maximum number of materials. Hall-Petch relationship says that yield stress is inversely proportional to the grain size. The relationship is depicted in figure 3.

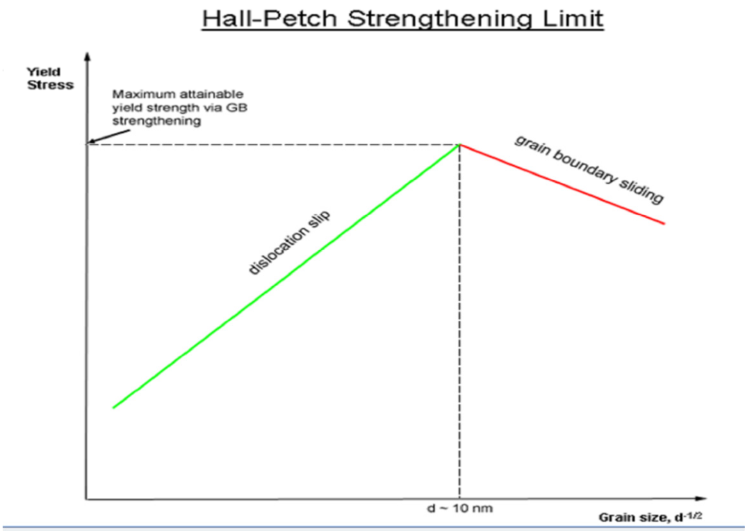

Fig: 3. Hall- Pitch strengthening Limit

3.2. Novel Property

1. Very small number of molecules is contained in the material
2. Confinement of the movement of the particles (Quantum confinement)
3. Nanoparticles, being of very small size, behave like wave-so wave particle duality is observed
4. Size being smaller, the small wavelength, high frequency, high energy properties is dominant.
5. Discrete energy levels are observed in nanomaterials

4. How Can Nanomaterials Be Formed?

Nanomaterials of different dimensions are produced in the manufacturing process; viz. zero dimensional nanomaterials like atomic clusters, one dimensional nanomaterials like nanotubes, nanorods, two dimensional nanomaterials like buried layers and also three dimensional such as nanophase materials.
Nanomaterials for aerospace are generally prepared by gas phase synthesis process.

Chemical Vapor Deposition[4] (CVD) –
CVD is a popular process of synthesis of nanoparticles where the substrate on exposure to the volatile gases, collect the precursors from the gases onto them and deposited layer is formed. This happens at high temperature in the CVD reactor. In homogeneous deposition, particles are deposited on the cold surfaces by the thermoforetic forces. Nanopowders can be collected from the surface or thin layer can be formed. This is what is called homogeneous method. In this method less reactive gases contain more reactive radicals at higher temperature than the substrate.
In heterogeneous CVD, solid of any form deposits on the surface. Nucleation occurs on the surface itself so that film structure is formed easily. To get film desirable film deposition, this the preferred synthesis method compared to homogeneous one. CVD process is the preferred process of synthesis of nanomaterials as this method has advantages over other methods. This allows the nanomaterials to deposit into verities of forms like powdered, thin film, thick film, coiled structure or any desired shape. Their size, shape, crystallinity can be controlled excellently. Relatively pure particles are formed in large scale. The growth parameters such as temperature, carbon rich gases and catalysts can be controlled significantly in this method.

5. Engineered Materials And Structures

Engineered materials are those which are not the same as produced but engineered or tailored as the need comes. The material properties of nanomaterials can be changed according to the need. That is an important feature that cannot be achieved by the conventional materials. Now energy storage components can be accomplished with nanomaterials and functionality is as a whole increased due to handling materials in nano range. The obvious result is the improvement in performance and efficiency while we can use light weight material with huge toughness, strength, electronic properties.

Engineered Materials And Structures Are Divided Into Five Areas:

i). Lightweight Structures: Structures having lightweight surrounds nanomaterials with functional and structural properties which allow the decrease in the weight of aircraft by enabling light weight nanomaterials and higher efficiency aircraft components[16]. These include long lasting structure, lightweight and high-efficiency wiring, data cables, and devices.

ii). Damage-Tolerant Systems: Damage tolerance and control can be possible introducing nanoparticles in the system that strengthen the interlaminar interfacial strength and repair fast. Stiffness, toughness, strength, ductility and smoothness should be achieved at a time. Damage should be controlled in unfriendly weather conditions, including high-impact events and vulnerability to high temperature.

iii). Coatings: Coating on a substance is a thin engineered layer of some other substance spread over it to prevent environmental risk, icing, dust and ionizing radiation. Coating can also protect the important parts from high temperature damaging[9].

iv). Adhesives (Nano additive): Adhesives are used in aerospace industry in the interior and exterior or in robotic inspection of spacecraft, satellite repairing orbital debris grappling and docking, low-precision rendezvous, astronaut extravehicular activity (EVA), and in-space assembly. These are used in the form of paste, liquid or film. These improve the durability, save weight, give challenging designs, and fuel efficiency for engines. Further high bonding quality can be achieved using nanotechnology in future.

v). Protection against high temperature: Thermal management system gives the lightweight approach to protect systems to get damaged due to uncontrolled thermal cycling.

6. Energy Storage, Power Generation, And Power Distribution

The application of nanotechnology in the field of energy has three branches; generation, storage and distribution[1]. Atomic and molecular level interactions are mostly involved in energy generation and storage. Hence the materials developed from the atomic or molecular level must serve the purposes for the same.

These Technologies Are Divided Into Three Areas:

i). Energy Storage: The advancement in the energy storage systems is observed a lot by the application of nanotechnology. Lithium ion batteries, ultra capacitors offer high power density and energy and are applicable in different missions. On the other side, nanomaterials can be used for preparing electrodes with increased electrolytes and reactivity with better transport properties. These materials or composites should also be able to operate at high temperature.

ii). Power Generation: Photovoltaic's and thermo photovoltaic can provide huge power for aircraft and habitats. Piezoelectric and thermoelectric devices can convert vibration or thermo power into electrical one. But the generated power is only a small amount. The efficiency of conversion is through by replacing the device components by nanocomposites and improving the mechanism of conversion of any power to electrical power.

iii). Power Distribution: Power distribution systems include buses, wiring, and harnesses for distribution and power management in spacecraft and aircraft. Nanotechnology can reduce the density of the storage systems and improved the durability by providing more durable conductive materials, lighter weight, and improve thermal management and insulation for wiring in energy distribution systems.

7. Propulsion

In propulsion system, nanomaterials enable new or increased existing capabilities[5,6]. This is possible in two different ways-

i). Propellants: Various propellant systems are hazardous and it is necessary to handle the propellants with care. Cryo-propellants and hypergolic propellants are mostly used now which can be replaced by nanomaterials derived propellants. These are less toxic and safe to use. By means of nanotechnology, the propellant transfer can also be made easy. This may greatly reduce launch costs, ground operations, and complexity.

ii). Propulsion Components: Nanomaterials can improve thermal conductivity, strength, and durability which enable the development of more efficient energy storage, long lasting, lighter components and propulsion systems of aircraft.

8. Nanomaterials And Nanocomposites For Storage

8.1. Composites

8.1.1. Carbon Nanotube (CNT) composites

CNTs have remarkable mechanical properties. They have greater Young's modulus, tensile as well as compressive strength, and extraordinary stiffness, very higher toughness. Their thermal property is also astonishing. These materials have changeable conductivity. Though the excellent mechanical properties do not reflect when composites are prepared with them. The load transfer capacity is hindered for several reasons. The dispersion the CNTs and filling them in composites are difficult. But due to the fast progress in composite science and technology, CNT composites will certainly serve as storage material. CNT reinforced polymer composites[3,7] have the potential to be used in aviation due to their high strength and low weight. They can be also useful to resist fire and vibration. Now the CNT-matrix interaction is of great interest and it is proved that functionalization of the CNTs with different chemical groups mediated via defects inside them facilitate strong bonding between the nanotubes filler and matrix material.

8.2. Nanostructured Metals

Nanostructured metals have high tensile and fatigue strength, high ductility, toughness and hardness compared to the conventional materials. So these can be effectively used as a substitute of toxic materials in coating technology. They can replace chromium as these are toxic materials and also for the potential of the nano metals for using them in anticorrosive coating materials. Though these can be used in delicate use like landing gear or other parts of spacecraft, these involve complex synthesis method and their ductility should be increased more before using them in suitable place.

8.3. Nanomaterial/Polymer Nanocomposites

Materials which is made up of two or more than two components which are in two or more than two phases are called composites. These two phases are one filler with one matrix material. Load conducting efficiency among the filler and the matrix determines the strength of the composite formed. For aircraft manufacturing nanofibres, graphene, CNTs or nanoclays are hugely used as fillers as shown in below Fig 4.

9. Nano-Composite Used In Building An Aircraft

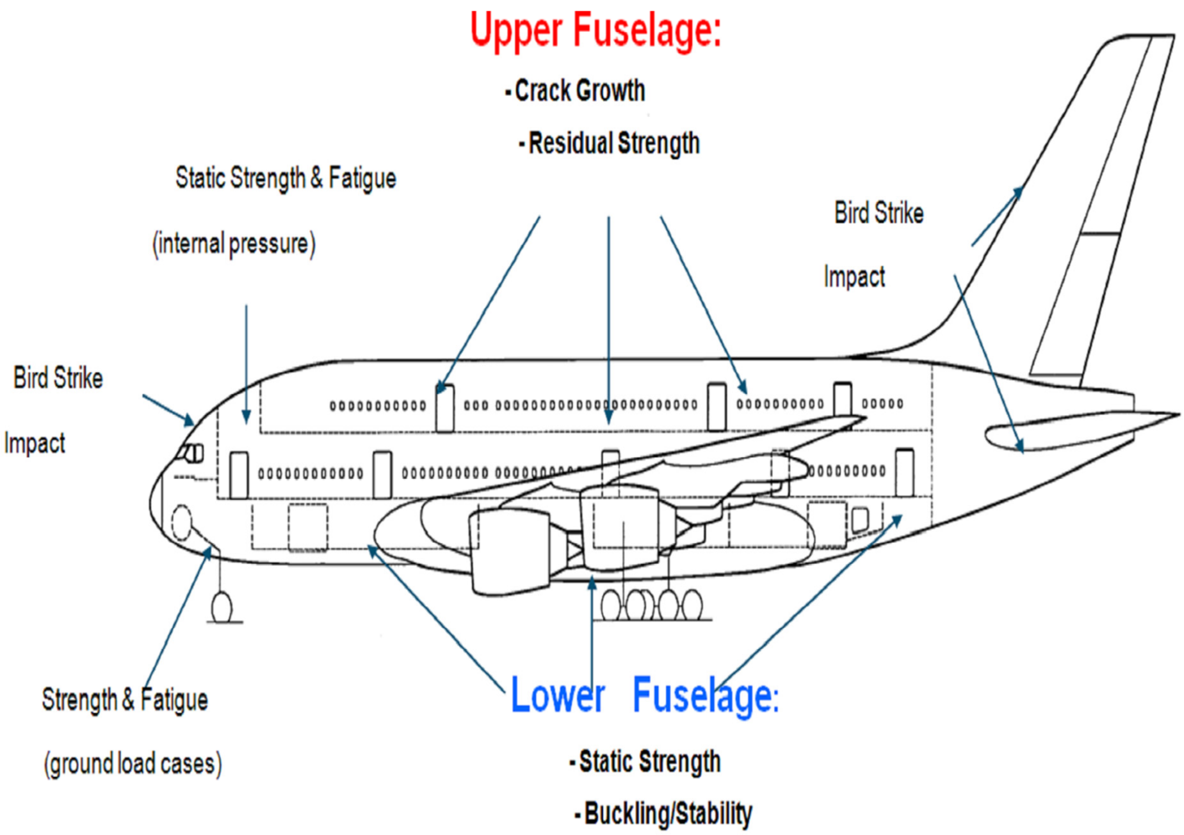

Fig: 4. Place where Nanomaterial can be used. (Source: Nanocomposite and Nanotechnology in Aerospace Research by Ion Dinca, Victor Manilou, Adriana Stefan, Ana Stan)

9.1. Materials Used For The Main Structure

- The materials to be used for the structure of the airframe must have the following properties
- They should have high strength and stiffness
- The materials should be light weight
- These should be anti corrosive
- Highly tough and durable material
- Should be easily reparable and reusable

9.1.1. Nano-Materials By Which The Requirements Can Fulfil:

Materials to be used should be nanomaterials as they possess extraordinary mechanical, electrical and thermal properties. Their properties can be tailored when needed by changing the manufacturing processes and parameters. Intelligent and smart materials can shape smart aircraft so that they are designed difficult to discoverable under radar and sonar. These eco-friendly, light weight and easily reparable materials are ideal for such applications.

9.1.1.1. SWCNT/Polymer Composites

Single Walled Carbon Nanotubes (SWCNT): Graphene sheets rolled along the chiral vector form seamless cylindrical structures called CNTs. Single walled, multi walled CNTs and bundles or ropes of CNTs are formed. They have very high Young's modulus around 1 TPa and high tensile stress around 100 GPa. Crash resistance is

very high too. They can bear a high temperature without failure. However, for directional property of the CNT based polymer composites alignment of the CNTs in the matrix material is required. Still, Only 1% addition of SWCNTs in a matrix, the stiffness can be increase between 35-43% and strength by 25%[10,11].
The probable reduction in the weight of the as well as aircraft using composite materials can be reinforced by the use of carbon nanotubes (CNT) which can be large up to 70% compared to conventional carbon fibre reinforced polymers[2,3].

9.1.1.2. Nano-Clays Reinforced Polymer Composites

The major problem of using CNTs to prepare CNT/polymer composites is their alignment as stated above. Good adhesion of the CNTs is necessary to achieve the goal. But this increases the production cost 10,000 fold. Still suitable industrial scale production process is lacking. Compared to this, due to nontoxicity, easy abundance and easily processability, nanoclay composites, in modern age have gained tremendous research interest. For example, small amount of nanoclay can improve the properties of Polyethylene composites considerably. When a small quantity of nanoclay is infused in between the filler and polymer, the overall strength of the composite increases. Thermal and Flame Retardant Barrier Properties are improved as well.

9.1.1.3. Metal Nanoparticles Incorporated Composites

From Hall-Pitch relationship, it is obvious that with the decrease of grain size, the strength of the metals increases.
• Nanostructured metals, like titanium or aluminium alloys, which can enhance the mechanical properties including strength and improve the corrosion resistance.
.• Nano Metals can be strengthened with the use of ceramic fibres like, carbide, aluminium oxide, silicon nitride or aluminium nitride. The advantages of these Metal matrix composites (MMC) are having higher thermal stability, greater strength, higher thermal conductivity, a low density, and a controllable thermal expansion. Metal matrix composites (MMC) have the potential to substitute aluminium and magnesium parts may be in the future

9.2. Aero-Engine Parts

As the research on aerodynamics has been progressing fast, the consumption of fuel is diminished considerably compared to the past. But still the air engines consume hydrocarbons as fuel. The visible progress is only in terms of more fuel-efficient engines and systems and also in term of reduction of weight figure 5[9,10,11]. Further improvements are required for the engines, fuel consumption cost and fuel quality.

- Enhancement in efficiency of the engine can be achieved by nano materials that allow lower engine weights, high pressures, higher operating temperatures, and increased rotor operating stresses.

- The nanoscale materials that can bear high temperature, have the potential to improve the quality of the engine material so that thrust-to-weight ratio is up to 50%. Using nanomaterials the fuel can also be saved up to 25% compared to the conventional engines.

- The engine blades are now coated with nanomaterials. Today's research is focused on the tailoring the properties of coating so that it can stick to the blades made of metal and help the engine run smoothly in heated condition.

- Thermal barrier coatings (TBC) can be applied on the metal blades to make the engines work at elevated temperature. TBC have common applications in gas turbines, aero engines, aero structures and chemical processing. TBC are two layered systems. The inner layer is made of perovskite oxide ceramic and it can resist strain. The outer layer, made of same material should be chemically resistant. For TBC, nanophase ceramics can be used as when the nanoparticles are in the range of 100 nm, they show extraordinary toughness.

Fig: 5. Engine Part (Source SAFRAN)

Airplanes move in such an environment that it have to pass through harsh environment. The coatings can protect the surfaces and structure of the airplane from harsh climate, corrosion, erosion, scratching or wearing of engine parts. For this, effective coating made of nanostructured materials can be proposed. Friction can be avoided using nitrides, carbides or metal nano particles.

- Yittria stabilized Nano-zirconia
- SiC Nanoparticles in SiC-particle-reinforced alumina.
- TiN Nano-crystallites embedded in amorphous Si_3N_4 is used as Wear resistant coatings.

10. Disadvantages Of Nano-Materials

(i) Disposal of nano-waste – Toxicity related issues are always alarming for nanomaterials. Hence the disposal of nano waste may be harmful for the environment. Experimental evidences of exposure associated results are very few. Therefore the uncertainty associated with the effects of Nanomaterials is yet to be assessed in order to develop the disposal policies.

(ii) Internal reaction caused by impurities – Though nanomaterials contain very lesser number of impurities in them, but naomaterials are so reactive that they interact with the impurities present in themselves.

(iii)Explosive nature- Nanoparticles, due to their large surface area are highly reactive and their combustion is exothermic. When comes in direct contact with atmospheric oxygen they act as strong explosives.

(iv) Production of suitable size of nanoparticle is difficult: It is very tough to maintain the size of Nano-particles when they are formed within the solution and thus, the Nano-materials have to be enclosed in matrix material.

(v) Biologically harmful– Nanoparticles, are easily absorbed by skin, they become transparent to the cell dermis. Absorption of the materials, due to low mass is very high when inhaled. Once trapped inside lungs, these are impossible to breathe out. Large surface area of the nanomaterials causes high reactivity as well as high toxicity. Nano-materials have shown to cause of irritation, and have indicated to be carcinogenic.

11. Conclusion

The above discussion shows that the potential of the Nano composite materials in Aviation Sector. Using nanotechnology or Nano Composite in aviation gives the High Strength, Light Weight, Corrosion Resistant, materials with high toughness and durability. Also these materials needs least maintenance and they are reusable. Cheaper and safer coating for the surface of the aircraft is easy with them. Unlike the conventional materials, these coating can protect the aircraft from harsh environment more efficiently. Made with the nanomaterials, the structure of the airplane can be repaired easily. In spite of having some disadvantages of nanotechnology, the overall gain can be counted indeed.

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