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Titanium: A New Generation Material for Architectural Applications

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Abstract
Advanced Materials are defined as unique combinations of materials, process technologies, that together, help create and capture value by addressing large, global unmet wants and needs of building industry. There is a wide range of innovation enabled by technologies for processing materials and integrating currently available materials for creation of new generation buildings "Titaniun" is one of them. It is an incredibly durable and stunning material known for its wide-range of color, high-tensile strength. Titanium can be processed to achieve a variety of surface textures, from a soft matte to a near gleaming reflectivity suitable for architectural application. Titanium's corrosion immunity, strength and physical properties combine to allow reduced wall thickness, lowering its installed unit cost which is favourable as far as its application in densely populated urban areas is concerned. Many countries like United Sates of America, China, and Spain etc have also stared its use however its use in developing country like India is still limited. The paper attempts to analyze the chemical properties of Titanium as a futuristic building material. It also observes the variant of the material as option to make self-cleaning buildings in the future, reducing the amount of harmful cleansers used currently.
Key words – Titanium, Anodizing, surface textures, recyclable.

I. Introduction -

Advanced Materials are defined as unique combinations of materials, process technologies, that together, help create and capture value by addressing large, global unmet wants and needs of building industry. There is a wide range of innovation enabled by technologies for processing materials and integrating currently available materials for creation of new generation buildings "Titaniun" is one of them. Occurs in the minerals ilmenite (FeTiO3) or rutile (TiO2) and Titaniferous magnetite, titanite (CaTiSiO5), and iron ores, titanium is the most noble metal which is highly resistant to environmental pollution, marine environments, which perform well in even more aggressive environments. It is an incredibly durable and stunning material known for its wide-range of color, high-tensile strength. Since it is strong and resists acids it is used in many alloys. Titanium dioxide (TiO2), is used in paint, rubber, paper and many other materials as well as used in heat exchangers, airplane motors, bone pins and other things requiring light weight metals or metals that resist corrosion or high temperatures. These properties make titanium a material suitable for architectural applications for futuristic buildings.

II. Historic Background

Titanium, is an element named after the "Titans" earth giants in ancient Greek mythology was discovered by Rev. W. Gregor in 1790. It was discovered from black magnetic sand found in Cornwall, south England by isolation of its Oxide. M.H.Klaproth a German chemist confirmed that rutile ore consisted of the same Oxide in year 1795 and assigned the name "Titanium" to it. American chemist M.A. Hunter successfully isolated titanium metal from titanium tetrachloride by reducing it with sodium which resulted in "Titanium metal". It was nearly a hundred years later (1887) when impure titanium was first prepared by Nilson and Pettersson. About 20 years later Hunter heated Titanium Chloride TiCl4 with sodium in a steel bomb and isolated 99.6% pure titanium. It is the ninth most abundant element in the earth's crust and is also found in meteorites and in the sun. It is found in the ash of coal, in plants and even in the human body. It occurs in the minerals rutile, ilmenite and sphene.

In year 1946 it was produced at large scale as a major industrial product in the form of sponge made with the process of reducing titanium tetrachloride with magnesium developed by W.J. Kroll who as a renowned chemist from Luxemburg. Later it was used in the aerospace, chemical, electric-power and other industries as well as in architectural, civil-engineering and general-purpose applications. Renowned architect Frank O. Gehry used Titanium as faced material in the Guggenheim Museum (Spain) in 1990, which made titanium the favorite material having exceptional aesthetical appeal (Fig.1).

Fig.1. Guggenheim museum Bilbao, Spain

Source: adventutte.howstuffworks.com Gehry's Guggenheim Museum Bilbao, with its distinctive titanium curves and soaring glass atrium, was hailed as one of the most important buildings of the 20th century. The architect chose to coat the surfaces facing the river with 0.3 mm thick sheets made of an alloy of titanium and zinc, with posses' outstanding durability and ductility as well as provide a better color than steel due to the cloudy climate of the city.

III. Chemical Properties

Titanium is a Block D, Group 4, Period 4 element. The number of electrons in each of Titanium's shells is 2, 8, 10, 2 and its electron configuration is [Ar] 3d2 4s2. The titanium atom has a radius of 144.8.pm and its Van der Waals radius is 200.pm. In its elemental form, CAS 7440-32-6, titanium has a silvery grey-white appearance. Titanium's properties are chemically and physically similar to zirconium, both of which have the same number of valence electrons and are in the same group in the periodic table. Titanium has five naturally occurring isotopes: 46Ti through 50Ti, with 48Ti being the most abundant (73.8%). n its metallic form, titanium is both strong and light weight, and it's highly resistant to corrosion. Thus it can be found in numerous aerospace and military applications. In its oxide form, it is used in low grades to produce a white pigment. Titanium is the basis for numerous commercially essential compound groups, such as titanates for electronic and di-electric formulations and in crystal growth for ruby and sapphire lasers. Fluoridesare another insoluble form for uses in which oxygen is undesirable such as metallurgy, chemical and physical vapor deposition and in some optical coatings. Titanium is also available in soluble forms including chlorides, nitrates and acetates.

Titaniumis produced with the use of "Kroll Proces" in which its ore (rutile sand) is treated with gaseous chlorine to form titanium tetrachloride (TiC14) then metallic magnesium is used to reduce TiC14 into titanium in a sponge form. The titanium sponge is then melted in a vacuum melting furnace to produce slabs or ingots with or without addition of titanium scarp. Then it is rolled into plates and rods.

3.1 . Anodizing and Oxidization

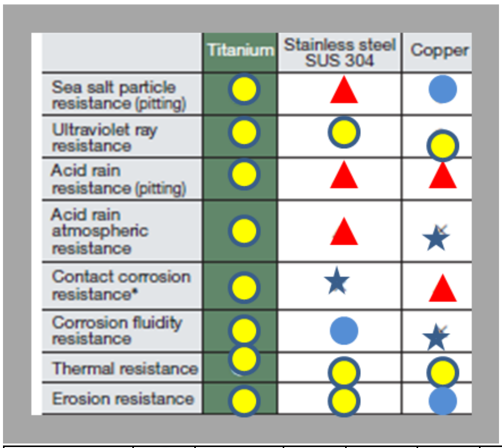
Titanium is generally used in its natural finish but for applications where other colour is required it can be anodized . Colour specifications can be met by anodizing the metal and by modifying the natural surface finish prior to anodising to vary the hue of a colour. The colour and finish are inherent to the film and the metal as a result of the anodising process. When titanium's natural clear oxide film is increased through anodic oxidation, colour is created by the phenomenon of light interference - the rainbow principle. As light rays travel through the film, they are partially reflected, refracted and absorbed. The reflected rays differ in phase, creating interference that gives the titanium colour. As the film thickness increases, the colour changes - from bronze, to green, to red-violet, through the full range of spectral colours. It offers outstanding corrosion resistance, and it requires no corrosion preventive coating. It possesses a subtle silver-grey colour having a pleasing appearance due to its soft reflectivity. The process of annealing and pickling the titanium induces the reflective metallic surface finish. Titanium can be processed to achieve a variety of surface textures, from a soft matte to a near gleaming reflectivity suitable for architectural application (Fig. 2,3).

Fig. 2. Cerritos Library, California. The new portion of the building is clad in titanium, the first building in the U.S. to use this material. It shimmers in the light and changes color with the weather.
Source: experienceology.wordpress.com

Fig.3. The Giant Mesh Wall acts like an air filter for mexico city.
Source: www.gizmodo.in

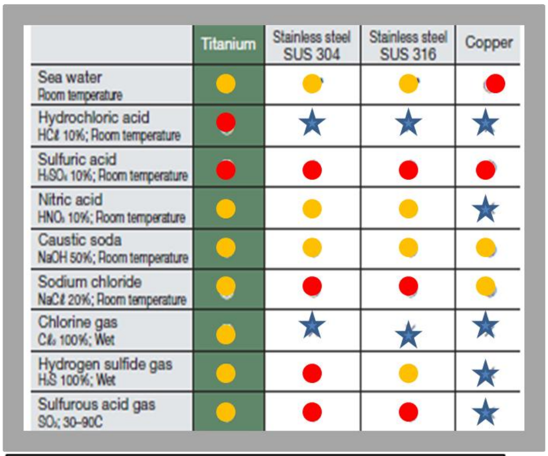
IV. Physical Properties

Titanium highly compatible to steel, copper and aluminum as it possess lowest thermal expansion. Titanium's coefficient of thermal expansion is half that of stainless steel and copper and one-third that of aluminum and equal to that of glass and concrete. The specific gravity of titanium is 4.51 g/cm3 - about 60% that of steel, half that of copper and 1.7 times that of aluminum. It is a lightweight metal which can be easily fabricated and installed with ease as well as it has less dead load. Because of its relative inertness in most atmospheres, titanium is considered environmentally friendly. It is 100% recyclable and the product of a renewable resource. It is durable and shock resistant having durable and shock resistant mechanical strength to steel. It is shock resistant and flexible than other architectural metals which perform well during earthquakes and other periods of violent movement. It is considered as a sustainable material having thermal conductivity of 10 Btu/hr.-°F/ft. which si is very low (one-tenth that of aluminum) increasing a building's energy efficiency. It has exceptional weather resistance as it is superior than platinum in sea water corrosion making it suitable for application in coastal areas (Fig.4,5).



Excellent	○	Good	●	Fair	▲	Poor	★

Fig.4. Weather Resistance of Titanium
Source: www.nssmc.com



Rating : ● ≤ 0.05 ● 0.05 ~ 0.5 ★ ≥ 1.27 mm/year

Fig.5. Chemical Resistance of Titanium
Source: www.nssmc.com

V. Titanium As Photo catalyst

TiO2 exists in three crystalline modifications: rutile, anatase, and brookite. Generally, titanium dioxide is a semiconducting material which can be chemically activated by light. The photoactivity of TiO2 which is known for approx. 60 years is investigated extensively. Under the influence of light the material tends to decompose organic materials. This effect leads to the well-known phenomenon of ”paint chalking”, where the organic components of the paint are decomposed as result of photocatalytic processes. Compared with rutile and brookite, anatase shows the highest photoactivity. Therefore, the TiO2 used in industrial products is almost exclusively from the rutile type. Although TiO2 absorbs only approx. 5 % of the solar light reaching the surface of the earth, it is the best investigated semiconductor in the field of chemical conversion and storage of solar energy. In recent years semiconductor photocatalysis using TiO2 has been applied to important problems of environmental interest like detoxification of water and of air(Fig.6).

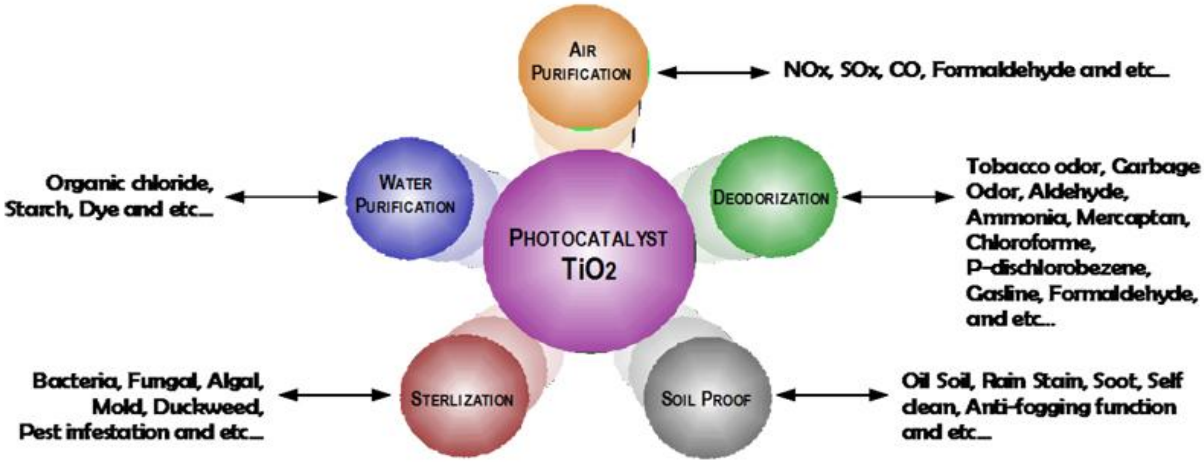


Fig.6 . Source: bioprocoatings.com

5.1 Photocatalysis

A typical semiconductor, TiO_2, creates holes and electrons by irradiating light with higher energy than TiO_2's band gap energy (wave length < 380nm). The holes and electrons react with oxygen and hydroxyl ions, producing hydroxyl radicals and superoxide anions. Oxidation power of the chemicals are so strong that the chemicals decompose and eliminate organic compounds and NOx.

VI. Photo-induced super-hydrophilicity

The surface coated with photocatalytic TiO_2 shows super-hydrophilicity by UV irradiation. On the super-hydrophilic surface, adsorbed water does not create dew but become thin layer. Thus, the surface exhibits anti-fogging effect and gets uneasy to be attached by stain itself. Furthermore, the surface becomes easy to wash away attached stain by water. The photocatalytic reactivity of titanium oxides can be applied for the reduction or elimination of polluted compounds in air such as NOx, cigarette smoke, as well as volatile compounds (Fig.7).

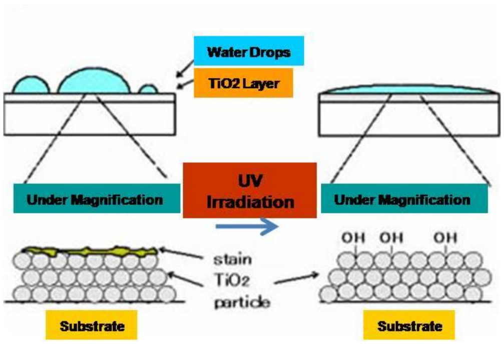
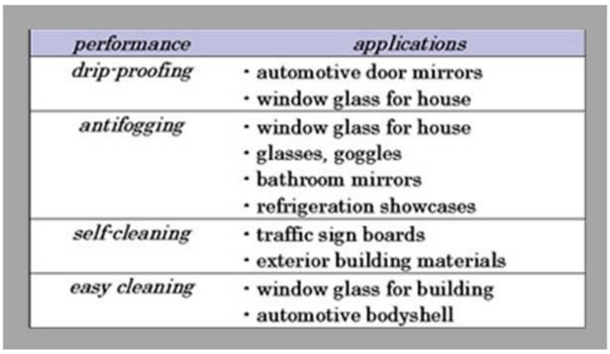


Fig.7 Mechanism of super-hydrophilicity



performance	*applications*
drip-proofing	・automotive door mirrors ・window glass for house
antifogging	・window glass for house ・glasses, goggles ・bathroom mirrors ・refrigeration showcases
self-cleaning	・traffic sign boards ・exterior building materials
easy cleaning	・window glass for building ・automotive bodyshell

Fig.8 Application

The heterogeneous photocatalytic oxidation with TiO2 meets the following requirements what could make it competitive with respect to other processes oxidizing contaminants:

- A low-cost material is used as photocatalyst.
- The reaction is quite fast at mild operating conditions (room temperature, atmospheric pressure).
- A wide spectrum of organic contaminants can be converted to water and CO2.

- No chemical reactants must be used and no side reactions are produced.

Photocatalysis has been used widely for purification of water and air. It has many advantages like ease of setup and operation at ambient temperatures, no need for post processes, low consumption of energy and consequently low costs as compared with traditional advanced oxidation processes. Titanium Dioxide (Oxide) UV-PCO Coatings are a potential solution against bio-airborne contaminants and pollution. It decomposes airborne and surface bacteria, mal-odors, biological contamination and microbial (mold) issues present in almost all building materials. Surfaces treated with TiO2 harness the natural power of light (UV or Full Spectrum) to help clean the exterior surfaces of building. It acts as an air purification system when applied in building interiors.

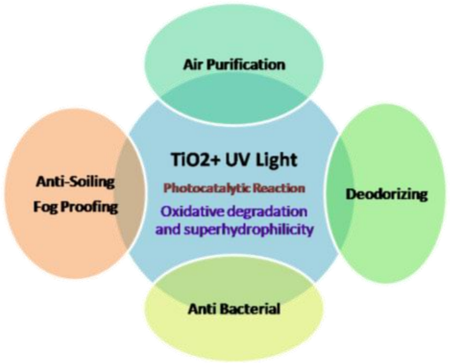


Fig. 9 Application of TiO2 Photocatalysis
Source: www.iskweb.com

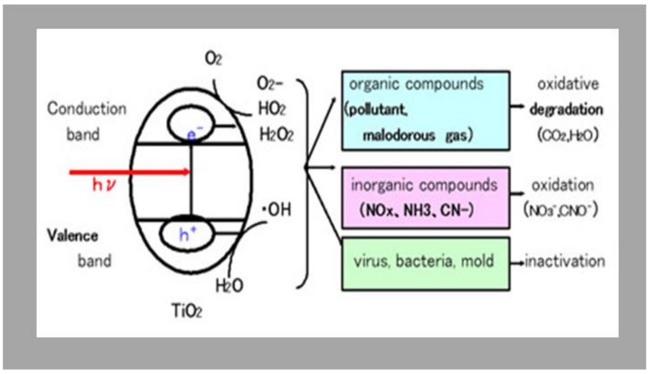


Fig. 10. Reaction Mechanism of TiO2 Photocatalysis
Source: www.iskweb.com

VII. Working of Photo Catalytic Oxidation (PCO)

Photocatalytic oxidation (PCO) is achieved when UV light rays combine with a Titanium Oxide (TiO2) coated filter. This process creates hydroxyl radicals and super-oxide ions, which are highly reactive electrons. These highly reactive electrons aggressively combine with other elements in the air, such as bacteria and Volatile Organic Compounds, which include harmful pollutants such as formaldehyde, ammonia and many other common contaminates released by building materials and household cleaners generally used. The chemical reaction takes place between the super-charged ion and the pollutant, effectively "oxidizing" (or burning) the pollutant. The pollutants break down into harmless carbon dioxide and water molecules, making the air more purified. Photo Catalytic Oxidation (PCO) is an advanced process by which volatile organic compounds (VOC's), bacteria, mold and fungus is destroyed by incorporating photon and ultraviolet (UV) energy activating a catalyst creating photo catalytic oxidation (PCO). PCO is produced by the air being exposed to photon light and passing through a catalyst comprised of specific nano-sized mineral compounds. After exposure and upon entering an area, three specific free radicals are released which destroys the bioaerosols (bacteria, molds, and fungus). During the process, hydrogen peroxide, hydroxyl radicals, and hydroxides attach themselves to specific organisms and kill them. This would be appropriate in places having high levels of microbial contamination as well as in automobiles with tobacco or musty odors.

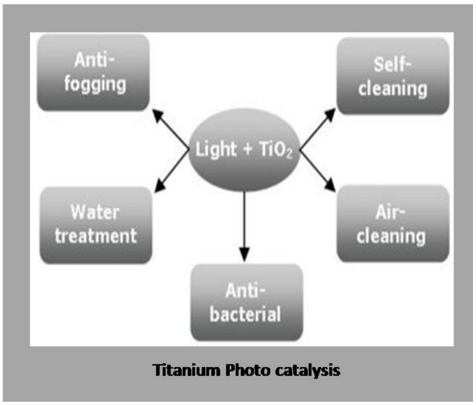


Fig. 11, www.cmbcontrol.com.mx

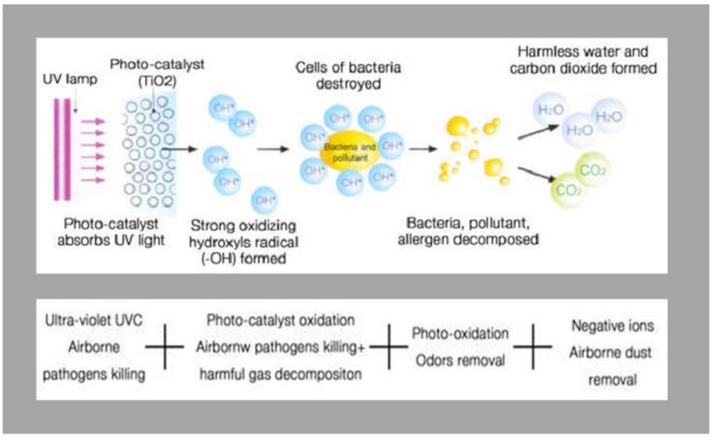


FIG. 12

VIII. Architectural Applications of Titanium

Architects began to use titanium in the 1970s. Its excellent corrosion-resistance properties make many architectural designs possible for structures in severely corrosive, salty atmospheres of coastal areas. It is widely used in various building types like museums, temples and shrines as well as in housing. Some of the applications in buildings are shown in figure 13, 14, 15, and 16 (Source: www.nssmc.com).

Fig. 13. The National Showa Memorial Museum is a national museum in Chiyoda, Tokyo: Titanium Aluminium Blasting Finish

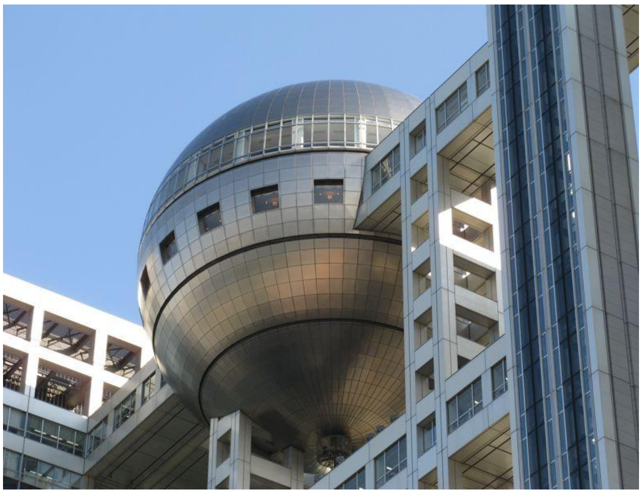


Fig. 14. Fuji Television Head quarter: Titanium Roll Dust Finish

Fig.15 Uchinada Town Center : Titanium Roll Dull Colour Finish

Fig. 16.Koetsuji Temple;:Titanium Aluminium Blasting Finish

The exterior of the Nathan and Fannye Shafran Planetarium designed by Westlake Reed Leskosky is surfaced with rose-colored titanium/stainless steel panels, the first use of the material on an exterior building in North America. Fiber-optic lights are embedded in each panel. At night, the lighting system gives the building a subtle glow (Fig 17,18).

Fig 17. Ti-Stainless on the Shafran Planetarium

Fig. 18. UNMC Tower with gold-tinted Ti

Buildings finished with titanium tested for their resistance against weathering and it has been found that in addition to excellent corrosion resistance they does not become discolored (Fig 19,20). TiO2 coated ceramic tiles are considered to be very effective against organic and inorganic materials, as well as against bacteria. The application of these tiles in hospitals and care facilities to reduce the spread of infections.

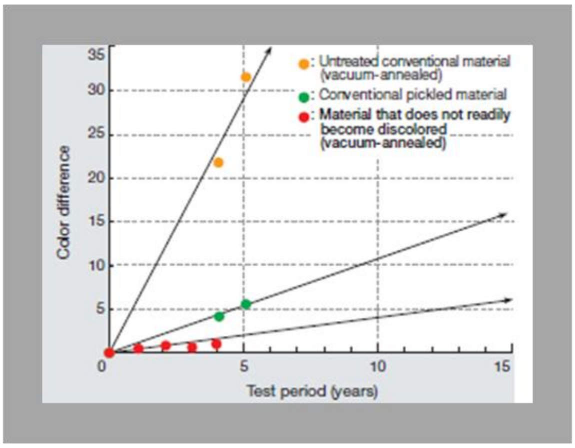


Fig. 19
Source: www.nssmc.com

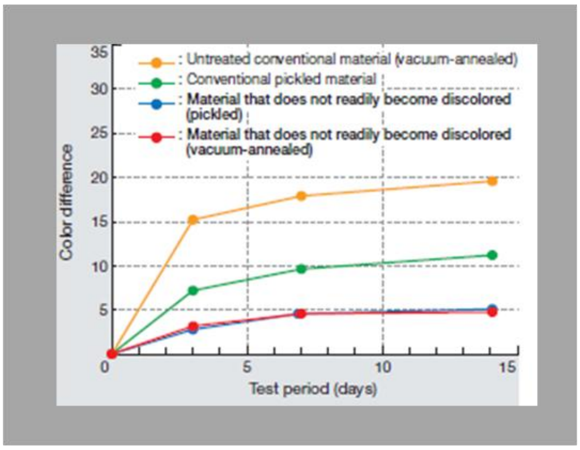


Fig.20
Source: www.nssmc.com

IX. Futuristic Applications

Nano-coatings containing titanium dioxide (TiO2) can make self-cleaning buildings in the future, reducing the amount of harmful cleansers used currently. Molecules of TiO2 have photo-catalytic properties. They release an electric charge when absorbing sunlight that forms reactive radicals, which oxidize the nearby organic (and some inorganic) substances when they exposed to ultraviolet and/or sun rays. The acidic products obtained in this process are washed away by rain or neutralized by alkaline calcium carbonate contained in the concrete. It is reported that nano-particles of TiO2 can even reduce air pollution by removing nitrogen oxides. Tests showed that road surfaces with incorporated nano-TiO2 reduce concentrations of nitrogen oxides by up to 60%. The use of nano-particles of Portland cement, silica (SiO2), titanium dioxide (TiO2), and iron oxide (Fe2O3) can significantly improve compressive and flexural strength of concrete [15]. In addition, nano-sensors can be integrated into concrete with the aim to collect performance data such as stress, corrosion of steel, pH levels, moisture, temperature, density shrinkage, *etc.*

X. Conclusion

Titanium with its beautiful soft gray finish could become the favorite metal used for architectural applications worldwide. Much like aluminum in its early stages, only its economic feasibility is standing in the way of a wider use in the building industry. Japan is currently the only country that has made an effort to use this metal in architectural applications at a larger scale. Many countries like United Sates of America, China, and

Spain etc have also stared its use however its use in developing country like India is still limited. Titanium has come of age as a competitive building material. New, more effective production techniques, combined with an abundance of raw and refined ore is required for an improved availability of the material for large scale use in building industry. Titanium's corrosion immunity, strength and physical properties combine to allow reduced wall thickness, lowering its installed unit cost which is favourable as far as its application in densely populated urban areas is concerned. Well-researched designs that capitalize on its unique attributes and long-term savings from durability and low maintenance make titanium one of today's most cost effective building materials on a lifecycle basis. It is supposed to be a sustainable solution for architectural applications in next generation buildings.

REFERENCES

[1.] A. Fujishima, K. Hashimoto, T. Watanabe: „*TiO2 Photocatalysis: Fundamentals and Applications";* BKC Tokyo; 1999.

[2.] Fujishima, K. Honda: „*Electrochemical Photolysis of Water at a Semiconductor Electrode*"; Nature 238 (1972) 37

[3.] Calkins, M. Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials; John Wiley & Sons: Hoboken, NJ, USA, 2009.

[4.] Chen, J.; Poon, C.S. Photocatalytic construction and building materials: From fundamentals to applications. *Build. Environ.* 2009, *44*, 1899-1906.

[5.] D. Bahnemann: „ *Solare Abwasserentgiftung*"; Nachr. Chem. Tech. Lab. 42 (1994) 378

[6.] Dirk Bockelmann: „*Solare Reinigung verschmutzter Wässer mittels Photokatalyse*"; Cuvillier Verlag; Göttingen 1994

[7.] URL: www.hydrotect.com

[8.] Green Technology Forum. *Nanotechnology for Green Building.* 2007. Available online: http://www.greentechforum.net/greenbuild/ (accessed on 2 June 2014).

[9.] Martinez, I.; Andrade, C. Examples of reinforcement corrosion monitoring by embedded sensors in concrete structures. *Cem. Concr. Compos*. 2009, *31*, 545-554.

[10.] Roland Benedix el al, "*Application of Titanium Dioxide Photocatalysis to Create Self-Cleaning Building Materials*"

[11.] W. Barthlott, C.Neihuis: „*Purity of the sacred lotus, or escape from contamination in biological surfaces"*; Planta 202 (1997) 1

[12.] www.cmbcontrol.com.mx

[13.] www.iskweb.com

[14.] www.nssmc.com

[15.] bioprocoatings.com

[16.] experienceology.wordpress.com

[17.] adventutte.howstuffworks.com