Nanomaterials: Classification and Properties-Part I

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Abstract:

It is well known recently that nanotechnology is one of the most exciting disciplines and it incorporates physics, chemistry, materialssciences, biology, medicine, tissue engineering, bones caffolds, cement and building materials, ceramic and bioceramics industries, biomaterials and many others. In this review article, the author interests with using the nanomaterials top repare the ceramic batches containing ultrafine and nono rawmaterials to indicate the importance of nanomaterials and/or nanoparticles for improving the physical and chemical, mechanical properties and resistance of the resulting bioproducts. In the future, it must increase the research points of both M.Sc.and Ph.D. These sonusing the industrial wastes or byproducts as raw materials in ceramic bodies to look for new and more effective ones using the most recent trend “Nanomaterials or Nanotechnology”.

Keywords:

Nanomaterials, Nantechnology, Nanophase, Nanostructure

1. Introduction

Recently, nanomaterials are cornerstones of nanoscience and nanotechnology. Nanostructure science and technology is abroad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionizing the ways in which materials and products are created and the range and nature of functionalities that can be accessed. It is already having a significant commercial impact, which will assuredly increase in the future (Figure 1).

Nanomaterials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge. These emergent properties have the potential for great impacts in electronics, medicine, and other fields (Figure 2).

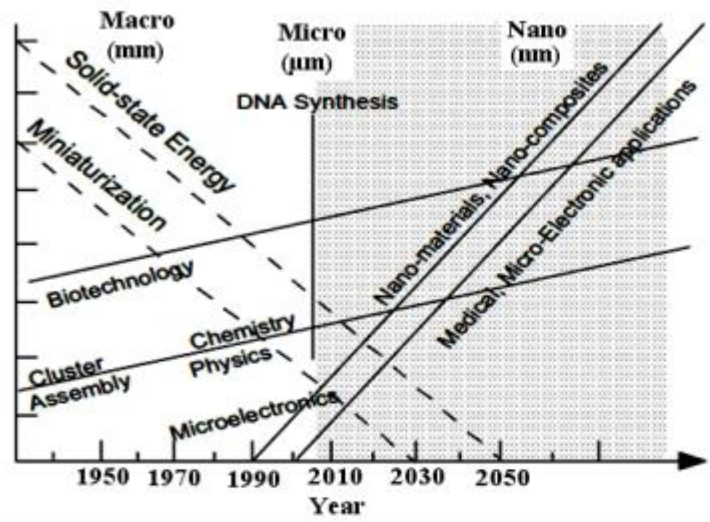

Figure 1. *Evaluation of science, technology and the future.*

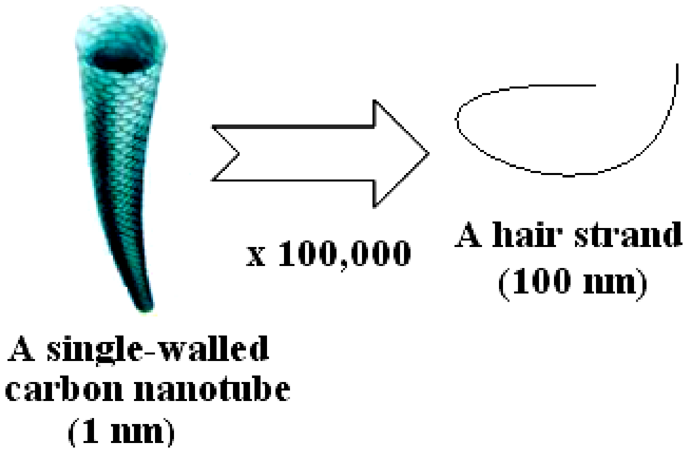

Figure 2. *A carbon nanotube as a nanomaterial.*

The meaning of “nanotechnology” varies from field to field and from country to country and it is widely used as a “catchall” description for anything very small [1-3]. Nanotechnology is commonly defined as the understanding, control, and restructuring of matter on the order of nanometers (i.e., less than100nm) to create materials with fundamentally new properties and functions [4-8]. Nanotechnology encompasses two main approaches: (i) the “top-down” approach, in which larger structures are reduced in size to the nanoscale while maintaining their original properties without atomic-level control (e.g., miniaturization in the domain of electronics) or deconstructed from larger structures into their smaller, composite parts and (ii) the “bottom-up” approach, also called “molecular nanotechnology” or “molecular manufacturing, ”introduced by Drexler et al. [7], in which materials are engineered from atoms or molecular components through a process of assembly or self-assembly (Figure3). While most contemporary technologies rely on the “top-down” approach, molecular nanotechnology holds great promise for break throughs in materials and manufacturing, electronics, medicine and health care, energy, biotechnology, information technology, and national security [9-16].

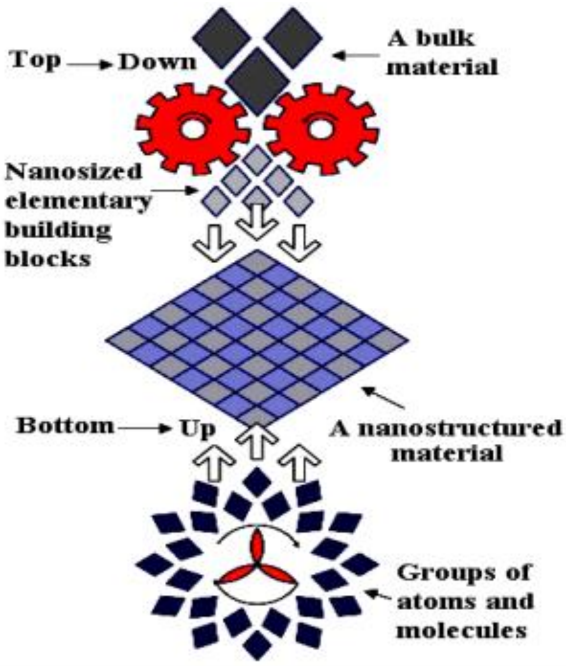

Figure 3. *The"Top-Down"and"Bottom-Up"approaches* innanotechnology.

There are other standards produced by Voluntary Standard Developing Organizations, most notably ISO, but no consensus has emerged yet about which set of definitions will prevail. However, it distinguishes between external dimensions and internal structures. Therefore an object can be larger than100nm in all three dimensions yet still be considered a nanomaterial if It has structural features within the nanoscale range [8-13].

Nanomaterials could be defined as a set of materials where at least one dimension is less than approximately 100 nanometers. A nanometer is one millionth of a millimeter approximately 100,000 times smaller than the diameter of a human hair [1,8,13,16].

The nanoscale is much too small for us to experience directly with our senses. As with chemical substances, nanoscale objects may be present in the working environment with little to alert the worker of a possible exposure. Just because you can't see it, feel it, smell it or taste it doesn't mean it's not there. Nano does not simply mean "very small". There are many forms of matter much smaller than a nanometer, including electrons, atoms and most molecules. The nanoscale is in between the very small atomic regime and the larger regime of microparticles and colloids.

1nm=0.000000001

m=10-9m

= One billionth meter

Some nanomaterials occur naturally, but of a particular interest are engineered nanomaterials, which are designed to be used in many commercial products and processes. They can be found in sunscreens, cosmetics, sporting goods, stain-resistant clothing, tires, electronics, as well as many other everyday items. They are also used in medicine for purposes of diagnosis, imaging and drug delivery. Engineered nanomaterials are resources designed at the molecular level (nanometer) to take an advantage of their small size and novel properties which are generally not seen in their conventional, bulk counter parts [1,8,16].

The two main reasons why materials at the nanoscale can have different properties are increased relative surface area and new quantum effects. Nanomaterials have a much greater surface area to volume ratio than their conventional forms, which can lead to agreater chemical reactivity and affect their strength. Also at the nanoscale, quantum effects can become much more important in determining the materials properties, leading to novel optical, electrical and magnetic behaviors. Nanomaterials are now used commercially. The range of commercial products available today is very broad including stain-resistant and wrinkle-free textiles, cosmetics, sunscreens, electronics, paints and varnishes. Nanocoatings and nanocomposites are already used in windows, sport equipments, bicycles and automobiles. There are novel UV-blocking coatings on glass bottles which protect beverages from damage by sunlight, and longer-lasting tennis balls using butyl rubber / nano-clay composites. Nanoscale titanium dioxide is applicated in cosmetics, sun-block creams and self-cleaning windows, and nanoscale silica which is being used as filler in several products as cosmetics and dental fillings [1,4,12,16].

2. History and Advances of Nanomaterials

The term nanotechnology was first used in 1974 by Norio Taniguchi to refer to the precise and accurate tolerances required for machining and finishing materials. In 1981, K. E. Drexler, now at the Foresight Nanotech Institute for Molecular Manufacture, described a new “bottom-up” approach, instead of the top-down approach discussed earlier by Feynman and Taniguchi. The bottom-up approach involved molecular manipulation and molecular engineering to build molecular machines and molecular devices with atomic precision. In 1986, Drexler published a book, Engines of Creation, which finally popularized the term nanotechnology. The term nano derives from the Greek word for dwarf. It is used as a prefix for any unit such as a second or a meter, and it means a billionth of that unit. Hence, a nanometer (nm) is a billionth of a meter, or 10^{-9} meters. To get a perspective of the scale of a nanometer, observe the sequence of images shown in Fig. 4. Despite the wide use of the word nanotechnology, the term has been misleading in many instances. This is because some of the technology deals with systems on the micrometer range and not on the nanometer range (1–100 nm). Furthermore, the research frequently involves basic and applied science of nanostructures and not basic or applied technology. Nanomaterials are also not undiscovered materials, but nanoscale forms of well-known materials such as gold, silver, platinum, iron and others. Finally, it is important to keep in mind that some past technology such as, for example, nanoparticles of carbon used to reinforce tires as well as nature’s photosynthesis would currently be considered a form of nanotechnology [17].

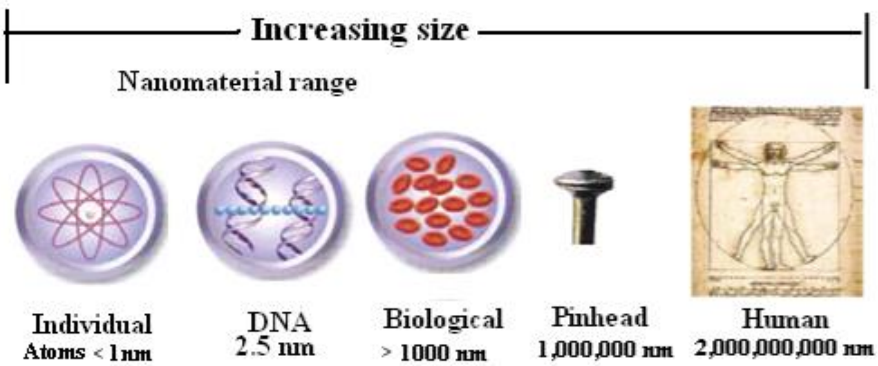

Figure 4. *Sequence of images showing the various levels of scale.*

The history of nanomaterials started immediately after the big bang when Nanostructures were formed in the early meteorites. Later, the nature released many other nanostructures like seashells, skeletons etc. Nanoscaled smoke particles were formed during the use of fire by early humans. However, the scientific history of nanomaterials started much later. Nanostructured catalysts have also been investigated for over 70 years. By the early 1940's, precipitated and fumed silica nanoparticles were being manufactured and sold in USA and Germany as substitutes for ultrafine carbon black for rubber reinforcements. Nanosized amorphous silica particles have found large-scale applications in many every-day consumer products, ranging from non-diary coffee creamer to automobile tires, optical fibers and catalyst supports. In the 1960s and 1970's metallic nanopowders for magnetic recording tapes were developed. In 1976, for the first time, nanocrystals produced now by the most popular inert- gas evaporation technique. Recently, the Maya blue paint is a nanostructured hybrid material. The origin of its color and its resistance to acids and bio-corrosion are still not understood, but studies of authentic samples from Jaina Island showed that the material is made of needle-shaped palygorskite (clay) crystals that form a superlattice with a period of 1.4 nm, with intercalates of an amorphous silicate substrate containing inclusions of metal (Mg) nanoparticles. The beautiful tone of the blue color is obtained only when these nanoparticles and the superlattice are present [4-8,12,16].

Today, the nanophase engineering rapidly expands to a growing number of structural and functional materials inorganic and organic, allowing to manipulate mechanical, catalytic, electric, magnetic, optical and electronic functions. The production of nanophase or cluster-assembled materials is often based on the creation of separated small clusters which then are fused into a bulk-like material or on their embedding into compact liquid or solid matrix materials. For an example the nanophase silicon, which differs from normal silicon in physical and electronic properties, could be applied to macroscopic semiconductor processes to create new devices. When the ordinary glass is doped with a quantized semiconductor "colloids", it becomes a high performance optical medium with potential applications in optical computing [12,13,18].

3. Results and Discussion

Nanomaterials have extremely small size which having at least one dimension ≤ 100 nm. Nanomaterials can be nanoscales in one dimension (eg. surface films), two dimensions (eg. strands or fibres), or three dimensions (eg. particles). They can exist in single, fused, aggregated or agglomerated forms with spherical, tubular, and irregular shapes. Common types of nanomaterials include nanotubes, dendrimers, quantum dots and fullerenes. Nanomaterials have applications in the field of nano technology, and displays different physical chemical characteristics from normal chemicals, i.e. silver nano, carbon nanotube, fullerene, photocatalyst, carbon nano, silica [9,12,19].

Nanostructured materials are classified as Zero dimensional (0D), one dimensional (1D), two dimensional (2D), three dimensionals (3D) nanostructures. where 0D spheres and clusters, 1D nanofibers, wires and rods, 2D films, plates, and networks and 3D nanomaterials (Figure 5). Nanomaterials are materials which are characterized by an ultra fine grain size (< 50 nm) or by a dimension limited to 50 nm. Nanomaterials can be created with various modulation dimensionalities as defined by Richard W. Siegel: zero (atomic clusters, filaments and cluster assemblies), one (multi-layers), two (ultrafine-grained over-layers or buried layers), and three (nanophase materials consisting of equiaxed nanometer sized grains).

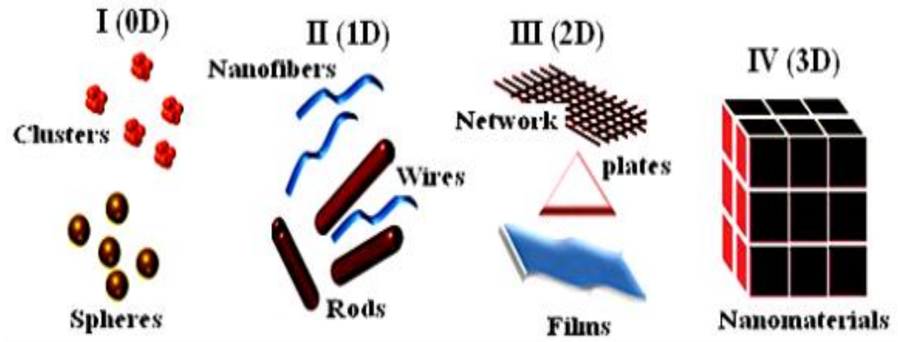

Figure5.I:(0D:Spheresandclusters),II:(1D:Nanofibers,wiresandrods),III:(2D:Films,platesandnetwork),V:(3D:Nanomaterials).

These nanomaterials have created a high and significant interest in recent years by virtue of their unusual mechanical, electrical, optical and magnetic properties. Some examples are given below:

i- Nanophase ceramics are of a particular interest because they are more ductile at elevated temperatures as compared to the coarse-grained ceramics [1,20-24].

ii- Nanostructured semiconductors are known to show various non-linear optical properties. Semiconductor Q-particles also show quantum confinement effects which may lead to special properties, like the luminescence in silicon powders and silicon germanium quantum dots as infrared optoelectronic devices. Nanostructured semiconductors are used as window layers in solar cells.

iii- Nanosized metallic powders have been used for the production of gas tight materials, dense parts and porous coatings. Cold welding properties combined with the ductility make them suitable for metal-metal bonding especially in the electronic industry.

iv- Single nanosized magnetic particles are mono-domains and one expects that also in magnetic nanophase materials the grains correspond with domains, while boundaries on the contrary to disordered walls. Very small particles have special atomic structures with discrete electronic states, which give rise to special properties in addition to the superparamagnetism behaviour. Magnetic nanocomposites have been used for mechanical force transfer (ferrofluids), for high density information storage and magnetic refrigeration.

v- Nanostructured metal clusters and colloids of mono- or plurimetallic composition have a special impact in catalytic applications. They may serve as precursors for new type of heterogeneous catalysts (Cortex-catalysts) and have been shown to offer substantial advantages concerning activity, selectivity and lifetime in chemical transformations and electrocatalysis (fuel cells). Enantioselective catalysis was also achieved using chiral modifiers on the surface of nanoscale metal particles [1,8,16].

vi- Nanostructured metal-oxide thin films are receiving a growing attention for the realization of gas sensors (NO_x, CO, CO_2, CH_4 and aromatic hydrocarbons) with enhanced sensitivity and selectivity. Nanostructured metal-oxide (MnO_2) finds application for rechargeable batteries for cars or consumer goods. Nanocrystalline silicon films for highly transparent contacts in thin film solar cell and nanostructured titanium oxide porous films for its high transmission and significant surface area enhancement leading to strong absorption in dyesensitized solar cells [2-5,8].

vii- Polymer based composites with a high content of inorganic particles leading to a high dielectric constant are interesting materials for photonic band gap structure.

N—in nanotechnology, a particle ranging in size from approximately 0.1 micrometer (100 nanometers) to .001 micrometers (1 nanometer). The term is most often used to describe aerosol particles such as those found in welding fumes and combustion by-products [1,5,8,16]. Ultrafine microstructures having an average phase or grain size on the order of nanometers (10^{-9} m) are classified as nanostructured materials [1,4]. Generally, in a wide meaning of the term, any material that contains grains as clusters below 100 nm, or layers or filaments of that dimension can be considered to be nanostructured [1,7]. The interest of these materials has been stimulated by the fact that owing to the small size of the building blocks (particle, grain or phase) and the high surface –to-volume ratio, these materials are expected to demonstrate unique mechanical, optical, electrical and magnetic properties [1,4,16]. The properties of nanostructured materials mainly depend on the following four common microstructural features:

i- Fine grain size and size distribution (< 100 nm).
ii- The chemical composition of the constituent phases.
iii- The presence of interfaces, more specially grain boundaries, heterophase interface, or the free surface.
iv- The interaction between the constituents dormant.

The presence and interplay of these four features largely determine the unique properties of nanostructured materials.

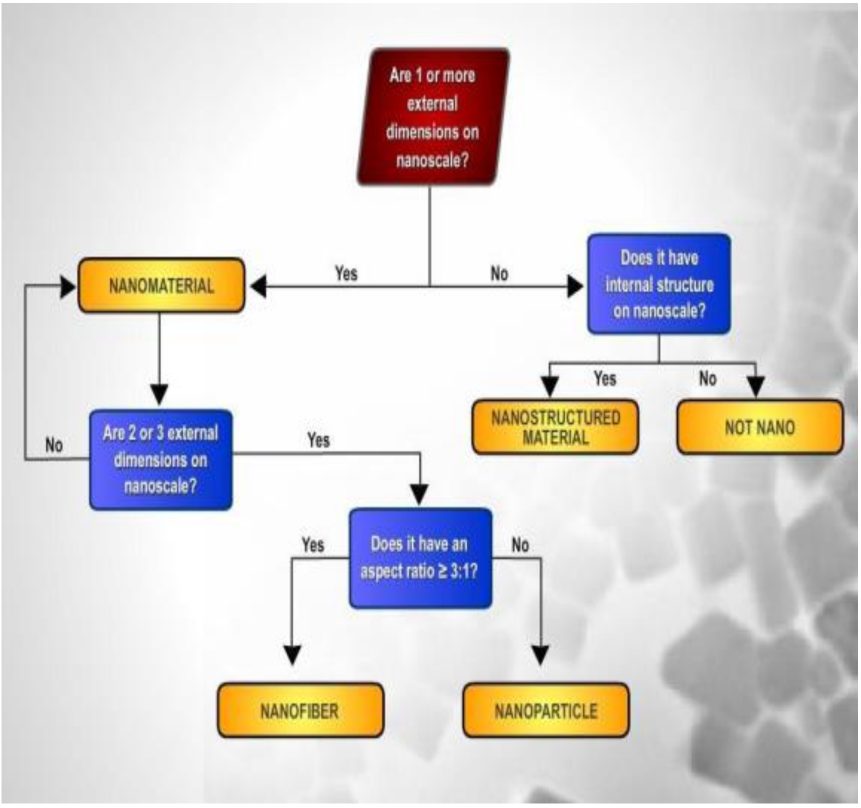

Figure 6. *The nanotechnology terms.*

Figure 6 indicates the uses OSHA and BSI criteria for nanomaterial, i.e. the ASTM definition of a nanoparticle and the BSI definition of a nanofiber. Nanofibers and nanoparticles can be called nanomaterials. They differ only in their length-to-width aspect ratio. Long and narrow objects are more accurately described as nanofibers whereas objects that are more spherical than needle-like are better described as nanoparticles. To be safe, one can simply call an object with one or more external dimensions on the nanoscale a nanomaterial.

4. Properties of Nanomaterials

Due to the unique properties of nanomaterials, particularly particle small size distribution and large surface area, various types of nanomaterials have been widely introduced into various types of matrices such as ceramic matrices [18], polymeric matrices [19] and cementitious matrices [20]. The main reason from dispersing nanomaterials into any matrix is to improve the properties of the composite such as mechanical properties [21], thermo-mechanical properties [22,23], etc.

5. Application

In terms of cement matrices, different nanomaterials can be used as supplementary cementitious materials in cement pastes, mortars and concretes. It was reported that the microstructure and performance of cement-based materials are influenced by the addition of nanomaterials. This is due to many factors such as the filer effect of nanomaterials to fill the voids between cement grains. Additionally, nanomaterials participate in the pozzolanic reaction or accelerate such reaction. This will leads to consumption of calcium hydroxide ($Ca(OH)_2$) and formation of an "additional" hydrated calcium silicates (C-S-H) gel [24]. Based matrices, different nanomaterials can be used as supplementary cementitious materials (SCMs) in cement mortars as well as in concrete. It was reported that the microstructure and performance of cement-based materials are influenced by the addition of nanomaterials. This is due to many factors such as the filer effect of nanomaterials to fill the voids between cement grains. Additionally, nanomaterials participate in the pozzolanic reaction or accelerate such reaction. This will leads to consumption of calcium hydroxide ($Ca(OH)_2$) and formation of an "additional" hydrated calcium silicates (C-S-H) gel [24]. The best improvements in the properties are the uniform dispersion of nanomaterials into the matrix. Well-dispersed nanomaterials affect as centers of crystallization of cement hydrates which results in accelerating the hydration of cement [23].

Depending on the type and quantity of nanomaterials, various mixing techniques were employed to disperse such nanoscale materials into cement composites. In case of carbon nanotubes, many studies were carried out to explore the dispersion method. The most popular method was sonication [25]. A group of researchers employed this technique to sonicate Ordinary Portland cement and Carbon nanotubes together in isopropanol and then dry the liquid. However, drawbacks were associated with this type of mixing as the surface grain of OPC was damaged which causes lower rate of hydration of cement [26]. Utilization of dispersing agents such as super plasticizers was suggested by other group of researchers [27] in order to increase the repulsive forces between adjacent colloidal particles when nanoparticles are added to water. In this case, materials tend to agglomerate when it contact with water.

6. Conclusions

It is well known recently that nanotechnology is one of the most exciting disciplines and it incorporates physics, chemistry, materials sciences, biology, medicine, tissue engineering, bone scaffolds, cement and building materials, ceramic and bioceramics industries, biomaterials and many others. The author interests with using the nanomaterials to prepare the ceramic batches containing ultrafine and nono-raw materials to indicate the importance of nanomaterials and/or nanoparticles for improving the physical and chemomechanical properties as well as the microstructures of the resulting bioproducts.

In the future, it must increase the research points of both M. Sc. and Ph. D. Theses on using the industrial wastes or byproducts as raw materials in ceramic bodies to look for new and more effective ones using the most recent trend “Nanomaterials or Nanotechnology”.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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