- Augmented reality
- Beat
- Control system
- Creativity
- Cultural density
- Digital signage
- Digital visual language
- E-bike
- Emergency intervention
- Interaction
- Interaction design
- Interface
- Mallification
- Mutant intervention
- Networking
- Open source
- Self-organisation
- Sensorial qualities
- Slow design
- Smart car
- Smart city
- Smart home
- Smart light
- Social innovation
- Social software
- Soft approach
- Systemic design
- Temporary intervention
- Test intervention
- Urban acupuncture
- Wikicity

Gas barrier
Nanotechnology
Self-cleaning
Self-repair

Unlimited nanotechnology

What's Nanotechnology, where does it come from and what can be done with it? Nature serves as inspiration for developing new nanostructures and nanomaterials with truly amazing properties, as well as an overview of the fields where nanotechnology can help achieve fascinating breakthroughs.
This article aims to explain different systems that use nanotechnology to maintain functional product properties for extended periods of time, resulting in longer useful product life cycles; to better maintain visual product appearance by reducing "premature product ageing" as perceived by users; or for self-repair purposes, to eliminate the need for product replacement or repair.

Heura Ventura

"Nanotechnology can help achieve a functional added value"

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What is "nanotechnology"?

The world of "nano"

In order to explain what nanotechnology is, we need to take a plunge into the world of "nano". The prefix "nano" comes from the Greek word *nanos*, which means "dwarf". Currently, "nano" is defined as one billionth of a part. For example, one nanometre is the result of dividing one metre by one billion equal parts, or equivalently, one millimetre by one million equal parts. The second example most likely gives us a clearer picture of the size range we are dealing with when talking about "nano-sized" things.

The nanoscale moves within a range of up to 100-200 nanometres (nm). A human hair is 90,000 nm in diameter, a red blood cell is approximately 7,000 nm in size, the wavelength of the visible spectrum of light ranges between 400 and 700 nm, a virus measures about 100 nm and DNA double helix measures around 2 nm. These comparisons give us an idea of nanotechnology's minuscule scale and also serve to introduce the most experienced and successful nanotechnologist known to mankind: nature.

Nanobiomimetics: Learning from nature

For millions of years, nature has practised binding different atoms to produce larger structures, giving rise to the principles of nanoscience. Using nanoscale-sized building blocks to create other macroscale-sized structures, nature has found a way to bind cellulose molecules to build fibres that are in turn used to build other larger materials such as cotton; proteins are bound together to create collagen fibres that are used to build tendons, cartilage, muscles, skin etc., among many other examples.

Also millions of years ago, nature provided Edelweiss flowers with filamentous nanostructures that make these flowers extremely resistant to ultraviolet radiation. Thanks to these nanostructures, Edelweiss flowers are capable of withstanding environmental conditions at high mountain altitudes (3,000 m above sea level), where they grow and thrive. Similarly, the nanostructured surface of moth eyes allows these insects to capture light in a more efficient way for enhanced nocturnal vision. These nanostructures have inspired scientists to come up with ideas on how to improve solar cell performance.

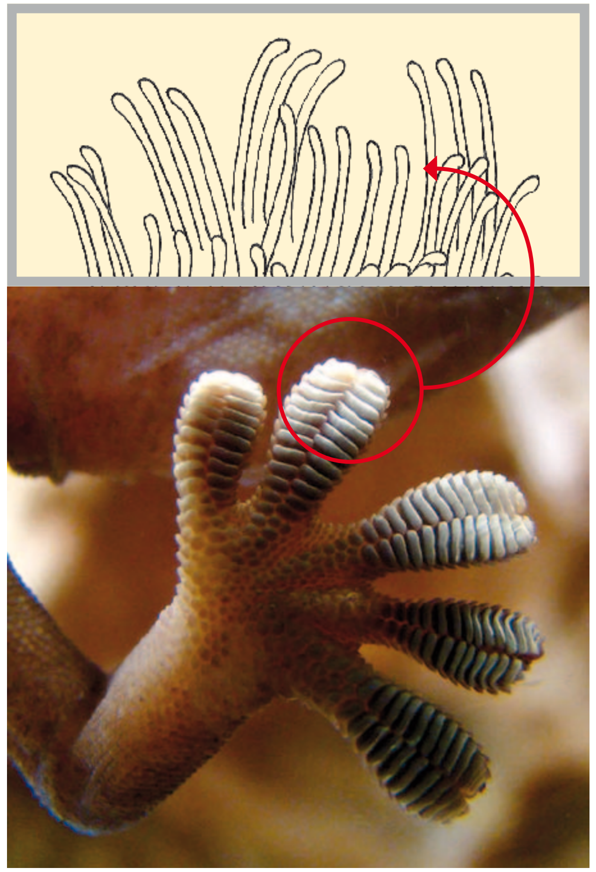
Also for millions of years, gecko lizards have been able to climb up walls and walk upside down thanks to feet filaments finer than human hair with multiple mushroom-shaped nanostructured terminations that stick to dry surfaces without the use of adhesive substances. In this case, nature has given us ideas on how to develop new nanostructure-based dry adhesive systems.

The leaves of lotus flowers are yet another example. These leaves have a rough surface with wax nanocrystals that confer superhydrophobic (water repellent) properties to this plant. As water droplets do not spread out across these leaves, they keep them clean by picking up any dirt particles they find along their path. This hydrophobic effect has inspired coatings devised to create stain-resistant, easy-to-clean or self-cleaning surfaces, which are very useful in applications such as furniture or car upholstery and work clothing.

Definition and applications of nanotechnology

Nanotechnology is an applied science that lets us create nanoscale-sized devices, materials and structures with astounding features. When factors such as specific surface or quantum effects come into play, materials acquire different properties within the nanoscale range than those otherwise displayed. In fact, materials such as gold, when reduced to nano-sized particles, have different optical properties (12-nm gold particles are not gold, but reddish in colour) and even different melting points (1060 °C for gold macroparticles, compared to around 650 ºC for gold nanoparticles).

Thanks to the study of nature and nanoscience research, we now have a better understanding of the nanoscale properties of materials and can apply nanotechnology to a number of fields, including[1]:



▲ Gecko feet filaments (below) and nanofilaments scheme about sticking to dry surfaces (above). © Wikipedia

“There are two basic approaches to obtain nanomaterials: top-down and bottom-up”

- Surface finishes such as anti-fungal, anti-bacterial, photocatalytic, anti-pollution, stain-resistant, water and oil repellent, self-cleaning or easy-to-clean, self-repairing, anti-fog, anti-reflective and even iridescent finishes.
- Reinforcement of materials to obtain nanocomposite materials. Reinforcements are found as nanoparticles or nanofibres, as well as other nanoscale-sized forms.
- In technological applications, nanotechnology helps us build more efficient solar cells, effective filtration systems, small monitoring devices, smaller and more powerful computers and mobile devices etc.
- In medicine, the use of nanoparticles is being studied to create new systems for diagnosing and curing cancer, as well as localised and controlled drug-delivery systems, among others.

These effects are largely achieved thanks to the application of nanomaterials such as nanoparticles, nanocoatings, nanostructured surfaces etc.

Nanomaterials manufacturing

There are two basic approaches to obtain nanomaterials: top-down and bottom-up.

The top-down approach starts with larger-than-nanoscale-sized particles or blocks and progressively removes excess material until both the desired shape and nanometric size are achieved. One could say that this method is similar to sculpting a block of marble, which starts with a large block from which excess material is removed until the desired shape is obtained. One example of the top-down approach is the lithographic process used to manufacture computer microchips.

Conversely, the bottom-up approach starts with small building blocks that are gradually arranged and assembled until the desired nanostructure or nanomaterial is obtained. In this case, an illustrating analogy would be that of the process of building a brick wall, where small building blocks (bricks) are piled up in a certain order to achieve the desired structure (wall). One example of this approach is chemical vapour deposition, where the interaction between a high-energy beam and a suitable gas produces nanoparticles that are deposited on a substrate, resulting in a coating that is only a few nanometres thin.

Nanotechnology and consumption

To a certain extent, today's consumption-based society “forces” the market to continually devise new astonishing proposals, solutions and technologies. We are increasingly surrounded by high-performance products and devices, in which technology plays a key role. A clear example of this is found in the field of communication technology, specifically the mobile technology sector, which has undergone a complete makeover within a very short period of time. Nowadays, mobile phones not only have to make users reachable 24/7, but also need to be lightweight, efficient, recyclable, and safe, as well as include Internet access, gaming and social networking applications etc. This also applies to computers and other electronic devices such as tablets and videogame consoles. In a context where remarkable progress is being made on a day-to-day basis, our technology-consuming society is eager to learn about new products with surprising new features, avidly seeking them out and taking great interest in them.

At present, nanomaterials have two basic applications: first and foremost, as polymer reinforcements to obtain plastic nanocomposites with fascinating and enhanced properties, but also as continuous-layer or nanoparticle-containing coatings that give special finishes to glass, walls, steel structures etc. These exciting properties and special finishes, coupled with society's thirst for new dazzling products, have given birth to an unmistakable interest in nanotechnology, given the enormous and highly functional value it can add to products.

As a result, nanomaterials research is growing exponentially, yielding an ever-increasing number of nanotechnology-based products. Furthermore, the breakneck pace of product research and development has in turn led to the wide-spread availability of materials (e.g. nanocomposites), which

1 Ashby, M. F; Ferreira, P. J.; Schodek D. L. “Nanomaterial Product Forms and Functions”. In: Ashby, M. F; Ferreira, P. J.; Schodek D. L. *Nanomaterials, Nanotechnologies and Design*. Oxford: Butterworth-Heinemann, 2009, p. 403-465.

have been made available even before knowing how to dispose of them at the end of their life cycle, or whether or not these materials involve any environmental or health risks. Despite efforts being made in this direction, a consensus on this matter has yet to be reached, as evidenced by a considerable number of research studies investigating the effects of nanoparticles on human health and the environment, compiled in literature review articles[2]; the creation or re-structuring of regulating bodies to oversee regulatory and legislation matters; and projects implemented to learn more about these nanomaterials[3], such as the Recytube Project[4] to assess the recyclability of carbon nanotubes, currently one of the nanoparticles of greatest interest. Admittedly,

> "One of nanotechnology's major focuses is to obtain nanofillers for polymer reinforcement"

it was not until recently that we became aware of these issues, with the lack of consensus being compounded by a generalised complaint regarding the lack of information and regulations. Surprisingly enough, nanotechnology has been within our reach without first having any testing, labelling or nomenclature standards in place.

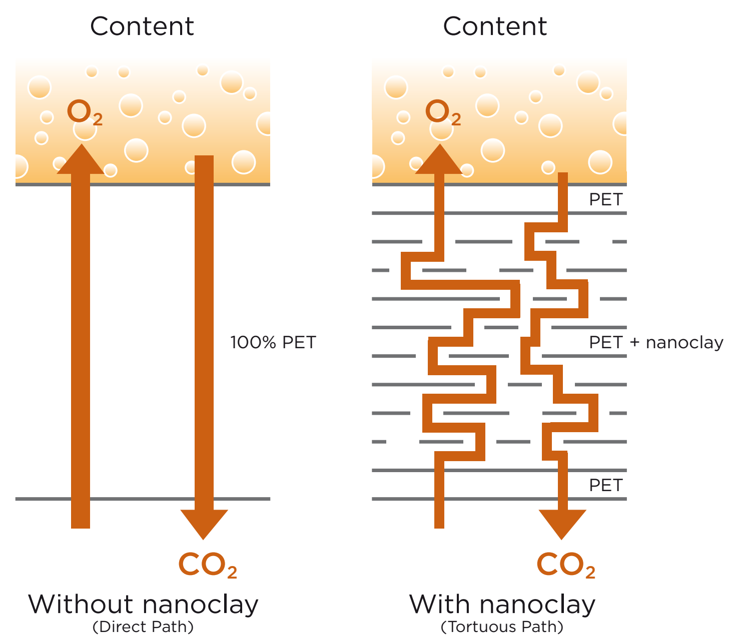
Therefore, the current trend in consumption can be summed up in one word: speed. Most products purchased are quickly replaced for other newer ones, as even the slightest change in their original appearance makes them seem like old products that need to be replaced or, at best, repaired, re-painted or embellished. Also, the launching of new products with improved features can lead to the product's "premature product ageing". Within this system and given the environment that has been emerging over the past few years, responsible consumers are looking for higher quality and value-added products, in an attempt to purchase the best products that may be kept in the best condition for the longest period of time. This is where nanotechnology can help achieve this functional added value.

How does nanotechnology help lengthen product life cycles?

Nanotechnology offers a huge array of options that are difficult to classify, as a single finishing product can sometimes produce several value-added effects. As regards products, nanotechnology can lengthen product life in three different ways: by maintaining functional product properties for longer periods of time, thus extending their useful life; by maintaining visual product appearance in better conditions, thus reducing "premature product ageing" as perceived by users; or by repairing products either by self-repair or by quicker and simpler repairs, avoiding costly replacements or procedures.

Nanotechnology to extend product functionality

As mentioned earlier, one of nanotechnology's major focuses is to obtain nanofillers (such as carbon nanotubes, fullerenes or nanoclays) for polymer reinforcement. In very small amounts – as little as 1-5% –, nanofillers can substantially modify the properties of the plastics to which they are added. But in addition to mechanical reinforcement (i.e. higher strength), nanoparticles can also improve other very interesting properties. For example, adding carbon nanotubes to plastic can make it tougher but also electrically conductive (even though polymers are insulators by nature). Similarly, nanoclay-reinforced polymers have greater flame resistance and display better gas barrier properties, among other effects, as compared to other non-reinforced polymers. Reinforced polymers can also be used as thin films or nanocoatings.



▲ Diagram 1

Two clear examples of products that have enhanced their functionality thanks to nanotechnology – with gas barrier properties prolonging their useful life – include tennis balls and soft drink bottles. In both cases, proper nanoclay dispersion in the polymer matrix creates a distribution of small elements that hinder the passage of gases. As shown in the diagram 1, gases would need to follow an intricate path to pass through the wall, making such passage a very difficult task. As such, gas permeability is reduced, preventing inner gases from escaping and outer gases from penetrating easily.

In sports such as tennis, the bounce of the ball is critical to the game. Tennis balls have a single inner rubber ball that contains air at a certain pressure (to ensure bounce). This rubber ball is then lined with fabric made of characteristic yellow filaments. Albeit low, the inner rubber ball does have some gas permeability; furthermore, inner pressure is not easily maintained due to strong impacts to the ball as the game is played. With use, tennis balls eventually stop bouncing properly, and without a mechanism for re-inflation, they are ultimately thrown out into the trash. Tennis balls are a product with a very limited life span. However, if we apply an inner nanosealer (a thin nanocoating film), we can create a gas barrier – using the same mechanism described above – that doubles the tennis ball's useful life[5]. This also cuts the need for product replacement in half, resulting in other environmentally friendly effects, such as lower waste disposal and reduced raw material requirements. The same concept can also be used to improve performance in products such as inner tubes. In this case, however, product life is not lengthened, but maintenance requirements are reduced (inner tube swelling).

Fresh food products (such as packaged meat), soft drinks and beer are industry sectors that are especially vulnerable to the effects of packaging gas permeability, as inefficient packaging materials that let gases either escape or penetrate can spoil the product. One way to extend the shelf life of these food products is to pack them using packaging materials that are capable of blocking the passage of gases. The applications of nanoclays in a variety of plastic matrices have been extensively studied to achieve proper gas barrier effects in food packaging. Studies have also been conducted to enhance gas barrier properties in polymers such as PLA[6] (a biodegradable plastic) to produce improved packaging containers that are more environmentally friendly

2 Maynard, A. D. "Nanotecnology: assessing the risks". *Nano Today*, vol. 1, No. 2 (2006), p. 22-33.

3 Karluss, T. et al. "FORUM. Research Strategies for Safety Evaluation of Nanomaterials, Part VIII: International Efforts to Develop Risk-Based Safety Evaluations for Nanomaterials". *Toxicological Sciences*, vol. 92, No. 1 (2006), p. 23-32.

4 Recytube Project [online]. [Consultation: June 20, 2012]. Available at: http://www.recytube.eu/

5 InMat Inc. Press release, 2001: "New technology doubles the life of tennis balls" [online]. [Consultation: April 13, 2012]. Available at: http://www.inmat.com/newsdocs/InMat-Press-release.htm

6 Picard, E.; Espuche, E.; Fulchiron, R.. "Effect of an organo-modified montmorillonite on PLA crystallization and gas barrier properties". *Applied clay science*, 53 (2011), p. 58-65

in terms of their final disposal. Also, adding certain nanoparticles (such as silver nanoparticles[7], which are known for their anti-bacterial properties) to plastic packaging materials[8], may result in active packaging[9] that helps preserve food for longer periods of time.

As another case in point, beer bottles are traditionally made of glass, specifically because of its impermeability to gases. Glass bottles, however, are heavy and fragile, making them difficult to transport. But conventional plastic bottles are not a feasible alternative either, due to their lack of suitable gas barrier properties. Thanks to nanotechnology, however, bottles with thin intermediate layers (nanosealers) containing nanoclays are now being produced, providing the appropriate conditions for the beer bottling process, as these nanosealers prevent oxygen from penetrating and carbon dioxide from escaping.

Nanotechnology to maintain good product appearance

For some time now, manufacturers have been selling refrigerators made with anti-fingerprint metal surfaces, or clothing made with water- and stain-repellent fabrics. From scratch-resistant anti-reflective coatings to anti-graffiti walls, nanotechnology has shown to have many applications where maintaining good product appearance is crucial. These applications, which usually make use of nanocoatings, extend product life by reducing the need for replacement due to deterioration in visual appearance. However, reducing the need for maintenance is also seen as a factor that may extend product life.

To further illustrate how nanotechnology helps reduce the need for product maintenance, below is a discussion on self-cleaning surfaces, which are closely related to easy-to-clean or anti-stain products, among other examples[10]. Self-cleaning surfaces can have one of two completely opposite systems: superhydrophobicity or hydrophilicity. These systems play with surface energy either to make fluids spread out easily, wetting the entire surface (hydrophilicity), or to make fluids remain as drops on top of the surface without wetting it (hydrophobicity). The resulting effect will be one or the other depending on the surface energy needed to create the liquid-air surface. If great energy is required and the solid-liquid surface energy is lower, liquid drops will tend to maximise contact with the solid surface, spreading out over such surface. Conversely, if little energy is required and the solid-liquid surface energy is higher, then the liquid drops will tend to minimise contact with the solid surface by taking a rounded shape.

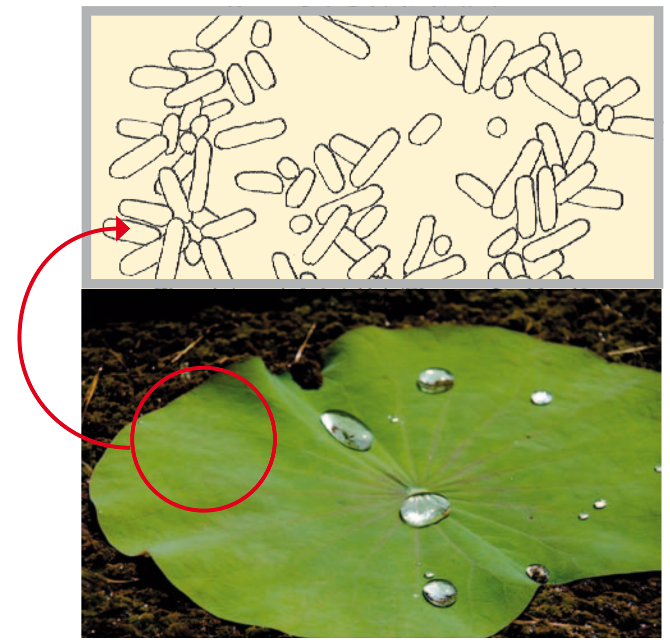
The superhydrophobic system mentioned earlier as an example of nanobiomimetics, is based on the lotus flower effect (diagram 2). It consists in achieving a surface that is water repellent to such an extent that drops of water (or stains) slide over the surface without wetting it. Water drops then carry any dirt, dust or other debris along with them as they slide over the surface, thus producing the self-cleaning effect. Anti-stain fabrics are one example of this system. These fabrics have a fluorocarbon-based surface finish that provides the finished side with superior hydrophobicity or water repellency. Therefore, when a drop of tomato or soy sauce spills

7 Robinson, Douglas K. R.; Morrison, Mark J. "Nanotechnologies for food Packaging: Reporting the science and technology research trends" [online]. Observatory NANO, August 2010. [Consultation: July 17, 2012]. Available at: http://www.observatorynano.eu/project/filesystem/files/Food%20Packaging%20Report%202010%20DKR%20Robinson.pdf

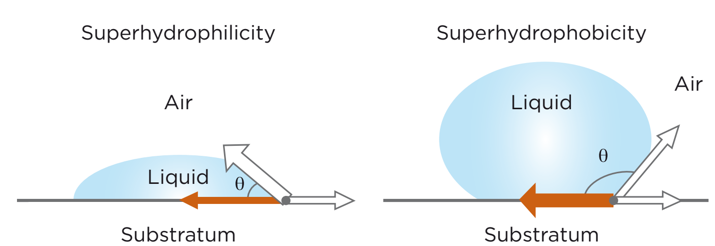
8 Soutter, W. "Silver Nanoparticles as Antimicrobial Agent". [online]. 2012. [Consultation: July 19, 2012]. Available at: http://www.azonano.com/article.aspx?ArticleID=3056 Will Soutter

9 Silvestre, C.; Duraccio, D.; Cimmino, S. "Food packaging based on polymer nanomaterials". *Progress in Polymer Science*, vol. 36, No. 12 (2011), p. 1766-1782.

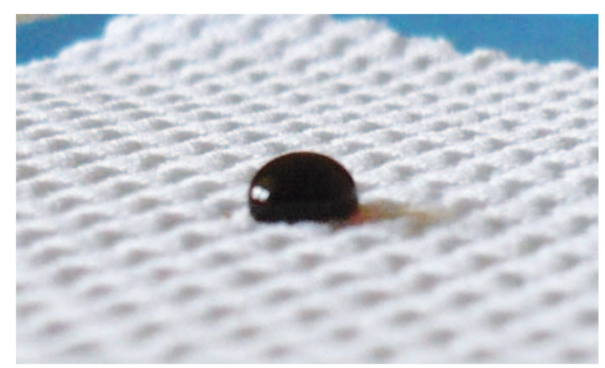
10 Greßler, S.; Fiedeler, U.; Simkó, M.; Gazsó, A.; Nentwich, M. "Self-cleaning, dirt and water-repellent coatings on the basis of nanotechnology". *Nano Trust Dossiers* [online], No. 20 (2010), p. 1-6. [Consultation: July 19, 2012]. Available at: http://epub.oeaw.ac.at/0xc1aa500d_0x0024fa56.pdf.



▲ The superhydrophobic system is based on the lotus flower effect. © GJ Bulte



▲ Diagram 2



▲ These fabrics have a fluorocarbon-based surface finish that provides the finished side with superior hydrophobicity or water repellency

on the treated surface, the stain slips until it falls off the fabric. The untreated side of this fabric can absorb water or sweat, making it both comfortable and practical. Fabrics with this type of finish can be used to manufacture upholstery, work clothing, ties, shoes etc., creating a wide array of products that need less washing and are easier to maintain. These fabrics can even extend product life considerably in products such as furniture that do not allow for the removal of fabrics for washing.

The second hydrophilia-based system is used on glass and walls to achieve the self-cleaning effect. In this case, water spreads quickly across the surface upon contact, wetting it and creating a thin film that falls by gravity like a curtain, sweeping up dirt and dust along the way. These finishes are made of titanium dioxide (TiO_2) nanoparticles, which may be applied as clear coatings to skyscraper glass windows or to the exterior walls of buildings. It is easy to see how these finishes help make skyscraper windows easier to clean or maintain simply by wetting them, but they are also extremely useful on car windshields, as they not only maintain visibility by keeping the windshield clean, but also improve visibility during severe rainstorms, thus providing car windshields with an added safety feature. As regards the second example, the application of these products to the exterior walls of building helps them stay cleaner longer, reducing the need to repaint façades, among other things.

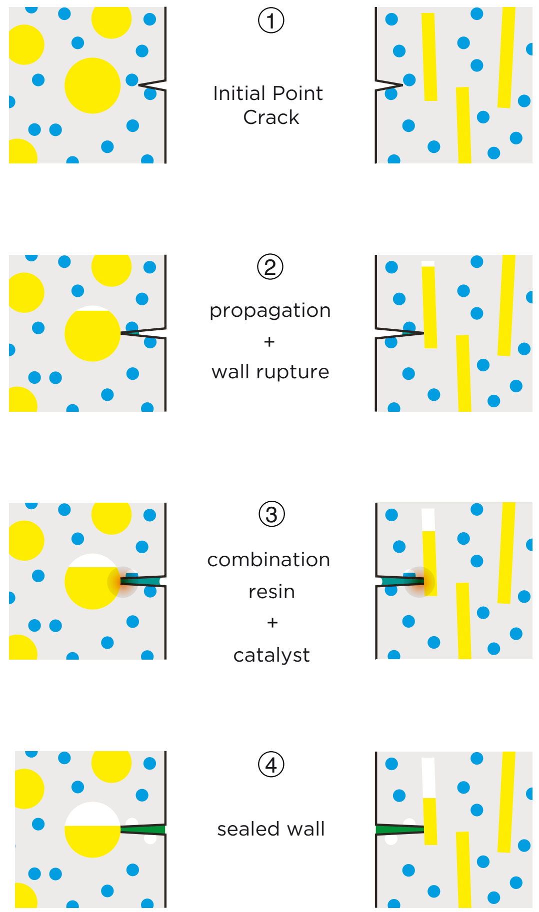
Thanks to their specific nature, TiO_2 nanoparticles not only provide these surfaces with self-cleaning properties, but can also help clean up the environment (anti-pollution effect) by preventing unsightly fungal growth on wall surfaces, thanks to their photocatalytic effect. This effect, which occurs when ultraviolet light interacts with TiO_2 nanoparticles, triggers an oxidation reaction of organic matter, affecting bacteria and fungi (preventing mould and mildew growth on walls), as well as volatile organic compounds and NO_x, which are common air pollutants in large cities. Given that these pollutants are reduced to carbon dioxide, water and other non-toxic products, these nanoparticles may also be used to create purification and odour-eliminating systems. This last example clearly shows how nanotechnology can add significant value to products.

Nanotechnology for product repair

There are some wax nanoparticle-based products that are currently being marketed as car scratch removers or polishers. However, one of nanotechnology's strongest future prospects is in the field of self-repairing materials, i.e. materials that include "smart" systems capable of reverting mechanical damage, among other things, without the need for costly procedures, the same way snails are able to self-repair cracks and damage to their shells.

Developing metal paint coatings capable of reverting damage caused by scratching or cracking is important because any deterioration of metal coatings can lead to corrosion of the underlying metal parts. As regards aesthetic damage, self-repairing coatings can also help save on money and raw materials by eliminating the need for automobile repainting. And in the case of certain construction blocks such as cement walls or slabs, the appearance of cracks can be fatal to the strength of the entire structure. As such, removing any damage to stress concentrators, thereby minimising the possibility of mechanical failure, could undoubtedly prove to be one of nanotechnology's most important applications. Self-repairing systems are still under study, but current knowledge suggests that sufficiently developed systems may become available in the not so distant future.

The most studied self-repair function[11] is based on the encapsulation of healing agents (essentially polymer resins) inside relatively fragile spheres or tubes. Both the capsules and small particles containing the proper catalyst for these agents, are added to the material. As cracks in the material become progressively larger, the capsules rupture and release a healing agent that reacts with the catalyst to produce a curing reaction that solidifies and seals the crack, as shown in the following diagram 3. Although most research studies have focused on microscale-sized capsules or tubes, some studies are currently investigating the development of nanocapsules[12].



▲ Diagram 3

11 Ashby, M. F.; Ferreira, P. J.; Schodek D. L. *Op.Cit.*

Cho, S.H.; White, S.R.; Braun, P.V. "Self-Healing Polymer Coatings". *Advanced Materials*, No. 21 (2009), p. 645-649.

12 Blaiszik, B.J.; Sottos, N.R.; White, S.R. "Nanocapsules for self-healing materials". *Composites Science and Technology*, No. 68 (2008), p. 978-986.

Conclusions

This article discusses several examples of how nanotechnology uses different mechanisms to help extend product life. Products using nanotechnology – a trend that seems to be on the rise – are already on the market.

However, we must not forget that before these products reach mass market levels, we need to have clear and effective regulations in place to allow for extensive use of these products without health or environmental risks. Nanomaterials are not hazardous *per se,* but we do need to take certain considerations into account, as with some chemical products, like batteries or drugs.

Using nanotechnology to add value to products allows us to produce more efficient, lower-maintenance and ultimately more environment-friendly products, but this needs to be done keeping the full product life cycle in mind. By doing so, we could provide for residue recovery, which could eventually lead to greater control and re-utilisation of nanomaterials (chain of custody system), in turn translating into substantial savings in both economic and environmental costs.

All of this leads to one main question: What is the final balance of using nanoparticles that are capable of killing both harmless and harmful bacteria, or nanoparticles that may involve risks if not properly controlled? And we need to ask ourselves this question because, in order to achieve revolutionary breakthroughs in science (and medicine), new developments need to take advantage of the "fascinating properties" that nanoscale-sized materials can offer, such as lower weight, greater efficiency, increased durability, enhanced properties etc. On this same note, it is important to underscore that in the 7th Framework R&D Programme of the European Union, a substantial number of lines of research focused on the study of nanotechnology and its risks[13].

"Using nanotechnology to add value to products allows us to produce more efficient, lower-maintenance and ultimately more environment-friendly products"

13 Fries, R.; Gazsó, A. "Research projects on EHS aspects of nanotechnology in the 7th Framework Program of the EU". *Nano Trust Dossiers* [online], No. 30 (2012), p. 1-6. [Consultation: July 17, 2012.]. Available at: http://epub.oeaw.ac.at/0xc1aa500d_0x002b2673.pdf