THE BENEFITS AND APPLICATIONS OF NANOCOMPOSITES

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ABSTRACT

The intensification in research of nanostructure materials in recent years has occurred primarily due to their attractive potential, that is mechanical and physical properties significantly improved compared to the conventional grain materials. At the most basic level of common understanding, nanoscience involves the study of materials where some critical property is attributable to an internal structure with at least one dimension less than 100 nanometers. This paper gave a broad definition of nanocomposites, nanofilbers, the benefits of nanocomposites, the processing, milestones in nano development, the strengths and limitations, as well as the various applications of nanocomposites. Due to the higher surface area available with nanofilbers, polymer nanocomposites offer the potential for enhanced mechanical properties, barrier properties, thermal properties and flame retardant properties when compared to conventionally filled materials. The knowledge of the immense value of nanocomposites will enable the manufacturers to recognise that polymer nanocomposites will herald a new era in materials advancement just as polymer composites transformed the face of industry many years ago. On the applications of nanocomposites, the paper explained that experimental work has generally shown that virtually all types and classes of nanocomposite materials lead to new and improved properties, when compared to their macrocomposite counterparts. Therefore, nanocomposites promise new applications in many fields such as mechanically-reinforced lightweight components, non-linear optics, battery cathodes and ionics, nanowires, sensors and numerous other systems.

KEYWORDS: Nanocomposites, nanotubes, electrospun, pelletization, polymerization.

1. INTRODUCTION

Materials and material development are fundamental to human's very culture. This explains why even major historical periods of the society are ascribed to materials, such as the stone age, bronze age, iron age, steel age (industrial revolution), silicon age and silica age (telecom revolution). This reflects how important materials are to people. People have and always will strive to understand and modify the world around them and the stuff of which it is made. The next societal frontiers will be opened not through understanding a particular material, but rather by understanding and optimizing the relative contributions afforded by material combinations. The nanoscale, and associated excitement surrounding nanoscience and technology (NST), affords unique opportunities to create revolutionary material combinations.

These new materials will enable the circumvention of classic material property trade-offs by accessing new properties and exploiting unique synergism between materials that only occur when the length-scale of morphology and the fundamental physics associated with a property coincide, i.e. on the nanoscale. The confluence of fundamental understanding of materials at this scale and the realization of fabrication and processing techniques that provide simultaneous structural control on the nano-, as well as micro- and macro-, length scales is the core of the exciting area of nano-engineered materials. Examples of such material technologies are rapidly increasing, impacting many diverse areas of the commercial and military arena.

One of the ways nanoscience has advanced the state-of-the-art has been to enhance and improve the properties of existing conventional classes of materials. Polymer composites, for example, have been a mainstay of high-performance aircraft for over a quarter century, offering a multitude of desirable (and tailorable) properties, such as high strength and stiffness, and dimensional and thermal stability. With the advent and application of nanotechnology, polymer composites could become even more attractive. As surely as polymer composites changed the face of industry twenty-five years ago, polymer nanocomposites will usher in a new era in materials development.

According to Cammarata (2006) Nanocomposites can be described as “multiphase materials where one or more of the phases have at least one dimension of order 100 nm or less.” He observed that as with conventional composites, the properties of nanocomposites can display synergistic improvements over those of the component phases individually. However, Okpala (2013) explained that nanocomposites “rapidly expanding field is generating many exciting new materials with novel properties.” He pointed out that the latter can be derived by combining properties from the parent constituents into a single material, and that there is also the possibility of new properties which are unknown in the parent constituent materials. In mechanical terms, nanocomposites differ from conventional composite materials due to the exceptionally high surface to volume ratio of the reinforcing phase and/or its exceptionally high aspect ratio. The reinforcing materials can be made up of particles (minerals), sheets (e.g. exfoliated clay stacks) or fibres (e.g. carbon nanotubes or electrospun fibres). The area of the interface between the matrix and reinforcement phase(s) is typically in order of magnitude greater than for conventional composite materials.

The matrix material properties are significantly affected in the vicinity of the reinforcement. Ajayan et al. (2003), observed that with polymer nanocomposites, properties related to local chemistry, degree of thermoset cure, polymer chain mobility, polymer chain conformation, degree of polymer chain ordering or crystallinity can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix. Commenting on the importance of nanocomposites, BBC research (2006) explained that “global consumption of nanocomposites has increased rapidly, reaching 23 million pounds in 2005, with an estimated value of $252 million.” They forecasted...
that by 2011, it is expected to reach almost 95 million pounds with an estimated value of $857 million. Experimental work has shown that almost all types and classes of nanocomposite materials gives new and improved properties, when likened to their macrocomposite counterparts. Therefore, nanocomposites promise new applications in many fields such as mechanically-reinforced lightweight components, non-linear optics, battery cathodes and ionics, nanowires, sensors and other systems.

2. THE BENEFITS OF NANOCOMPOSITES

Due to the high corrosive nature of metals used in oil and gas pipelines, and failure rate of conventional materials the importance of nanocomposites cannot be over-emphasised, this is because nanocomposites are materials with a nanoscale structure that improve the macroscopic properties of products. In mechanical terms, nanocomposites differ from conventional composite materials due to the exceptionally high surface to volume ratio of the reinforcing phase and/or its exceptionally high aspect ratio. The reinforcing material can be made up of particles (e.g. minerals), sheets (e.g. exfoliated clay stacks) or fibres (e.g. carbon nanotubes or electrospun fibres). The area of the interface between the matrix and reinforcement phase(s) is typically an order of magnitude greater than conventional composite materials. The matrix material properties are significantly affected in the vicinity of the reinforcement. In their study, Ajayan et al (2003) noted that with polymer nanocomposites, properties related to local chemistry, degree of thermostet cure, polymer chain mobility, polymer chain conformation, degree of polymer chain ordering or crystallinity can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix. This large amount of reinforcement surface area means that a relatively small amount of nanoscale reinforcement can have an observable effect on the macroscopic properties of the composite. For example, adding carbon nanotubes improves the electrical and thermal conductivity. Other kinds of nanoparticulates may result in enhanced optical properties, dielectric properties, heat resistance or mechanical properties such as stiffness, strength and resistance to wear and damage. In general, the nano reinforcement is dispersed into the matrix during processing. The percentage by weight (called mass fraction) of the nanoparticulates introduced can remain very low (on the order of 0.5% to 5%) due to the low filler percolation threshold, especially for the most commonly used non-spherical, high aspect ratio fillers (e.g. nanometer-thin platelets, such as clays, or nanometer-diameter cylinders, such as carbon nanotubes).

According to Azonano (2009) Nanocomposites can greatly enhance the properties of materials as it leads to the formation of nanoscale aluminate secondary phases in aluminium alloys, thereby increasing their strength and corrosion resistance. He further explained that magnetic multilayered materials are one of the most important aspects of nanocomposites, as they have led to significant advances in storage media.

Nanocomposites are becoming very popular today due to the enormous benefits being derived from it, this explains its acceptability and why leading manufacturing companies are spending millions of dollars on its research and development. The objectives of the project is to conduct a thorough research on the topic and then look for better approach to manufacture better and more durable nanocomposite products for oil and gas pipelines, that will serve as better alternatives to metal and other conventional materials.

3. NANOFILLERS

In his work, Zapata (2008) explained that polymer nanocomposites are “hybrid materials composed of an organic polymer matrix with dispersed inorganic filler that has at least one dimension in the nanometer range”. These nanofillers, with a very high aspect ratio, strongly modify the macroscopic properties of the polymer even when a small amount of filler is used. So nanocomposites usually have improved properties compared to neat polymers, such as better mechanical properties and higher thermal stability. Among the most commonly used nanofillers for obtaining nanocomposites are layered silicates, especially 2:1 phyllosilicates that are present in the form of sheets about one nanometer thick and hundreds to thousands of nanometers long. The layers are in turn linked together by Van der Walls forces and organized in stacks with a regular gap between them called “interlayer or gallery”. As the forces that hold the stacks together are relatively weak, the intercalation of small molecules between the layers is easy. In order to render these hydrophilic phyllosilicates more organophilic, the hydrated cations of the interlayer can be exchanged with cationic surfactants such as alkylammonium or alkylphosphonium.

When the clay is modified, its surface energy is lowered and it becomes more compatible with organic polymers. Zapata (2008) observed that Due to the lack of polar groups in polyolefins, many efforts have been made to improve the dispersion of inorganic fillers like clay and silica in a polyolefin matrix for the preparation of the effective polyolefin nanocomposites.

A significant amount of industrial and governmental research has been conducted on nanocomposites. The most popular polymers for research and development of nanocomposites are polyamides, polypropylene, polyethylene, styrenics, vinyls, polycarbonates, epoxies, acrylics, polybutylene terephthalate, and polyurethanes as well as a variety of miscellaneous engineering resins.

According to Maniar (2007), The most common filler is montmorillonite clay; these nanoclays are unique since they have a platy structure with a unit thickness of one nanometer or less and an aspect ratio in the 1000:1 range. Unusually low loading levels are required for property improvement. Expected benefits from nanocomposites include improvement in modulus, flexural strength, heat distortion temperature, barrier properties, and other benefits and, unlike typical mineral reinforced systems, they are without the conventional trade-offs in impact and clarity.

4. PROCESSING OF NANOCOMPOSITES

Polymer nanocomposites are a class of materials that use fillers possessing dimensions on a nanometer scale reinforced into the polymer matrix. These
materials blend a nanofiller with a polymer to produce a composite with equal or better physical and mechanical properties than their conventionally filled counterparts but with lower loadings of fillers. Due to the higher surface area available with nanofillers, polymer nanocomposites offer the potential for enhanced mechanical properties, barrier properties, thermal properties and flame retardant properties when compared to conventionally filled materials.

Currently practiced processes for forming nanocomposites generally include individual steps for polymerizing each of the various monomers followed by pelletization of each of the various polymers thus formed separately. After the individual polymers are pelletized, the formed pellets may be mixed with a nanofiller material in an extruder to form the nanocomposite material. While this process may be efficient for forming nanocomposites, at some instances they appear to be relatively expensive. Three dimensional metal matrix composites, two dimensional lamellar composites and one dimensional nanowires and zero-dimensional core-shells all represent the various nano-mixed and layered materials. This method of construction combines the best properties of each of the components or gives rise to new and unique properties for many advanced applications.

Nanocomposite could also be produced by dispersion of multi-layered silicate material into a thermoplastic polymer at a temperature greater than the melting or softening point of the thermoplastic polymer. The thermoplastic polymer is selected from the group consisting of a thermoplastic urethane, a thermoplastic epoxy, polyester, nylon, polycarbonate and their blends. **Carbon nanotube-reinforced composites**

Published reports reveal that carbon nanotube-reinforced composites could be synthesized using a powder mixing process with a powder-powder blending between carbon nanotubes and ceramic powder or raw metal like aluminum or copper matrix followed by a conventional sintering process. However, characterization of these carbon nanotube-reinforced composite materials has shown a decrease in mechanical properties. In particular, the relative density of the sintered composite materials becomes very low, ranging from 85% to 95%, which is important since low relative density means the existence of many fracture sources, such as pores and defects, which could be result in low mechanical properties. The reasons behind these problems are due to severe agglomeration of carbon nanotubes on the metal powder surface and the use of conventional consolidation processes. However, carbon nanotubes agglomeration in a metal matrix could be prevented by homogeneous dispersion of carbon nanotubes in the metal matrix. For homogeneous dispersion, carbon nanotubes may be dispersed in a predetermined dispersing solvent like water, ethanol, nitric acid solution, toluene, N,N-dimethylformamide, dichlorocarbene and thionyl chloride to form a dispersed solution, which is further treated with ultrasonic wave. Water-soluble metal salts or metal hydrates are mixed with the ultrasonic wave treated dispersed solution, dried to remove water vapor, hydrogen, nitrogen and finally calcinated to produce a stable carbon nanotube / metal oxide nanocomposite powder.

Metal nanocomposite powders can be used as high-valued abrasive materials or wear-resistant coating materials. The metal nanocomposite powder could further be applied in industrial fields which utilize conventional metal composite materials, such as the aerospace, high-performance machine parts, and medical industry, because it has high sintering performance and easily becomes bulky.

5. **MILESTONES IN NANO DEVELOPMENT**

Recently, advances in the ability to characterize, produce and manipulate nanometer-scale materials have led to nanocomposites’ increased use as fillers in new types of nanocomposites. Nanocomposites have attracted tremendous attention due to their potential applications in biomedical, catalytic, separation, chemical sensing, fuel cell, capacitor, microfabrication, tribological, resonant coupling, high flux gas transport and etc. Nanocomposite materials are complex of nanophase materials and other materials; it optimizes the performance of traditional materials. Various nanocomposites have been synthesized in a wide range of polymerization, sol-gel, deposition, magnetron sputtering, supercritical fluid, sonochemistry, laser, etc. Among these work, many strategies were addressed to improve nanocomposites mechanical properties by inclusions (fibers, whiskers, platelets, or particles). The embedding of inclusions in a host matrix to make composites, which gives material properties not achieved by either phase alone, has been a common practice for many years. Traditionally, composites were reinforced with micro-sized inclusions. Recently, processing techniques have been developed to allow the size of inclusions to go down to nanoscale. With the recent developments in the nanoscience and nanotechnology fields, the correlation of composite properties with nanostructure has become a point of great interest. As a result, much of the work is still ongoing and there is yet to be a definite conclusion on the effect of nano-sized structure on nanocomposite systems. Manufacturers now mix nanoparticulate metals, oxides and additional materials with polymers and other matrix materials to optimize the composite’s properties with respect to color/transparency, conductivity, flame retardancy, barrier properties, magnetic properties and anticorrosive properties, in addition to tensile strength, modulus and heat distortion temperature. These composites offer users significantly enhanced properties compared to conventional composite and noncomposite materials.

6. **STRENGTHS AND LIMITATIONS OF NANOCOMPOSITES**

Nanoparticles have an extremely high surface to volume ratio which dramatically changes their properties when compared to their bulk sized equivalents. It also changes the way in which the nanoparticles bond with the bulk material. The result is that the composite can be many times improved with respect to the component parts. Some nanocomposite materials have been shown to be 1000 times tougher than the bulk component materials. These explain its adoption and why it is playing a prominent role in manufacturing. There are a few disadvantages associated with using nanoparticle viz.
toughness and impact performance. Some researches have shown that nanoclay modification of polymers such as polyamides could even reduce impact performance. There is a need for better understanding of formulation/structure/property relationships to platelet exfoliation and dispersion etc. The improved properties vis-à-vis the disadvantages of the nanoparticles & resultant composites are shown in Table 1.

Table 1: Important Characteristics of Nano-composites

<table>
<thead>
<tr>
<th>Source: Demetrakakes (2002)</th>
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<tr>
<td><strong>Improved properties</strong></td>
</tr>
<tr>
<td>Mechanical properties (tensile strength, stiffness, toughness)</td>
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<tr>
<td>Gas barrier</td>
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<tr>
<td>Synergistic flame retardant additive</td>
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<tr>
<td>Dimensional stability</td>
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<td>Thermal expansion</td>
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<td>Thermal conductivity</td>
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<td>Ablation resistance</td>
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<td>Chemical resistance</td>
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<td>Reinforcement</td>
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Real world applications for nanocomposites are coming slowly. Nanocomposites Prove (2002), observed that there appears to be a reluctance to embrace this new technology due to cost and variability in the quality of some of the products. They pointed out that John Jones, a market development specialist at Honeywell, believes that manufacturers of these materials have to prove to the market that these new materials can meet their performance expectations.

Another challenge nanocomposite producers face is the production of the nanocomposite itself. Both methods, pre-polymerization and post polymerization, for preparing nanocomposites have drawbacks. The Nanoparticle News (2003) explained that “Pre-polymerization production can disrupt the polymerization process, which is often critical and requires much developmental time and expense to achieve good yields and controllability, and post polymerization often requires a lot of time to achieve a good dispersion of the nanoparticles in the composite”. This then becomes an expensive and low-cost-competitive initiative.

Commenting on the limitations, Demetrakakes (2002), stated that “another concern deals with equipment conversion that accepts new material through recalibration; this is a big investment for converters to make.” He explained that it is a complicated process to go from plastic pellets to a blown bottle, as it requires heating and blowing that form to the shape of the bottle. This is expensive equipment, very high-speed equipment, designed for the material that you’re going to run. You can’t just take another material with different flow characteristics, crystallization rate, and those kinds of things, throw that in there and make it run.

To date one of the few disadvantages associated with nanoparticle incorporation has concerned toughness and impact performance. Some of the data presented has suggested that nanoclay modification of polymers such as polyamides could reduce impact performance. Clearly this is an issue which would require consideration for applications where impact loading events are likely. In addition, further research will be necessary to, for example, develop a better understanding of formulation/structure/property relationships, better routes to platelet exfoliation and dispersion etc.

7. APPLICATIONS OF NANOCOMPOSITES

Experimental work has generally shown that virtually all types and classes of nanocomposite materials lead to new and improved properties, when compared to their macrocomposite counterparts. Therefore, nanocomposites promise new applications in many fields such as mechanically-reinforced lightweight components, non-linear optics, battery cathodes and anodes, nanowires, sensors and other systems.

Such mechanical property improvements have resulted in major interest in nanocomposite materials in numerous automotive and general industrial applications. These include potential for utilisation as mirror housings on various vehicle types, door handles, engine covers and intake manifolds and timing belt covers. More general applications currently being considered include usage as impellers and blades for vacuum cleaners, power tool housings, mower hoods and covers for portable electronic equipment such as mobile phones, pagers etc.

Nanomer nanoclays provide plastics product development teams with exciting new polymer enhancement and modification options. With the proper choice of compatibilizing chemistries, the nanometer-sized clay platelets interact with polymers in unique ways. Application possibilities for packaging include food and non-food films and rigid containers. In the engineering plastics arena, a host of automotive and industrial components can be considered, making use of lightweight, impact, scratch-resistant and higher heat distortion performance characteristics.

Oil and Gas Pipelines

Corrosion has a costly and deleterious effect on aging infrastructure throughout the world. As such, considerable attention has been focused on innovative techniques to arrest corrosion in the carbon steel found in pipelines, bridges, and water systems. In the United States, the annual cost associated with corrosion damage of structural components is greater than the combined annual cost of natural disasters, including hurricanes, storms, floods, fires and earthquakes. Similar findings have also been made by studies conducted in the United Kingdom, Germany, and Japan.

According to the U.S. Department of Transportation Office of Pipeline Safety (2009), “between 1989 and 2008 pipeline corrosion incidents resulted in over $582M in property damages, 28 fatalities and 94 injuries.” The need to manage and mitigate corrosion damage has therefore rapidly increased, as materials are placed in more extreme environments and pushed beyond their original design life. Corrosion damage and failure are not always considered in the design and construction of pipeline systems. Even if corrosion is considered, unanticipated changes in the environment in which the structure operates can result in unexpected corrosion damage. Moreover, combined effects of corrosion and mechanical damage, and environmentally assisted material damage can result in unexpected failures due to the reduced load carrying capacity of pipelines.
The application of nanocomposites is becoming increasingly important in the manufacture and structural repair of damaged pipelines. In their work, Kessler and Goertzen (2009) pointed out that nanocomposites offer more advantages in pipelines manufacture, while its overwraps are used to repair corroded steel pipelines, as the repair can be completed in a relatively short period and the fluid transmission in the piping system can remain undisrupted while the repair is being made.

Fiber-reinforced nanocomposite pipelines are emerging as a feasible alternative to steel pipelines with regard to performance and cost. The pipeline is typically constructed including an inner non-permeable barrier tube that transports the fluid (pressurized gas or liquid), a protective layer over the barrier tube, an interface layer over the protective layer, multiple glass or carbon fiber composite layers, an outer pressure barrier layer, and an outer protective layer. It is a nanocomposite structure in the purest engineering sense of the term, as each of the several components provides a distinct function and the interaction between the components produces a structure with exceptional performance characteristics.

The pipeline has improved burst and collapse pressure ratings, increased tensile strength, compression strength, and load carrying capacity, compared to non-reinforced, non-metallic pipelines. The ability of re-inforced nanocomposite piping to withstand large strains allows the piping to be coiled such that long lengths can be spooled onto a reel in an open bore configuration.

In addition, the pipe can be manufactured with fiber optics, copper signal wires, power cables or capillary tubes installed directly into the structural wall of the piping. This offers the option of manufacturing the pipe with embedded sensors and operating it as a so-called smart structure. Sensors embedded in the pipe can be powered via copper wire from remote locations and real-time data from the sensors can be returned through fiber optics. This provides the unique advantage of lifetime performance monitoring of the pipe.

According to Mays (2007), the application of reinforced nanocomposites in oil and gas pipelines has the following advantages:

- Anisotropic characteristics of nanocomposite piping provide extraordinary burst and collapse pressure ratings, increased tensile and compressive strengths, and increased load carrying capacities.
- No welding and minimal joining - many miles of continuous pipeline can be emplaced as a seamless monolith.
- Emplacement requirements should be dramatically less than for metal pipe, enabling the pipe to be installed in areas where right-of-way restrictions are severe.
- Structurally integrated sensors provide real-time structural health monitoring and could reduce need for pigging.
- Corrosion resistant and damage tolerant.
- Meets or exceeds published and consensus standards for pipeline in oil and gas applications.

Automobiles

The basic idea in implementing the nanocomposites in mechanical stream is the resistant to fracture and the often occurrence of wear and tear of the machine parts. Nanocomposites used as a blend against plastics can be used for strengthening the portions of the automobiles where higher efficiency is required. As the world is affected by the pollution the automobile manufacturers are working towards developing a technology which controls the same cost effectively, this led to the acceptance of polymeric nanocomposites. Owing to their polymeric nature, polymer nanocomposites fit this description. Because of their nanometer size features, polymeric nanocomposites possess unique properties, such as enhanced mechanical, impact, barrier and heat resistant properties, compared to other composites. Combining the unique properties of nanocomposite and recyclable polymers to produce light-weight recyclable and biodegradable polymer/nanocomposite is a great challenge. These compositions were widely used for making the body parts of the automobiles. The industry was mainly concerned over the following aspects:

- Weight reduction
- Improved performance
- Aesthetics
- And recyclability

Nanotechnology is already driving changes throughout this industry at nearly every level involving material, components, and systems. This is because most cars produced in the United States contain some nanomaterial, most typically carbon nanotube in nylon blend for the use of the fuel system to protect against static electricity.

According to Buchholz (2003) a plastic nanocomposite is being used for “step assists” in the General Motors Safari and Astro vans as it is scratch-resistant, light-weight, and rust-proof, and generates improvements in strength and reductions in weight, which lead to fuel savings and increased longevity. And in 2001, Toyota started using nanocomposites in a bumper that makes it 60% lighter and twice as resistant to denting and scratching.

Nanocrystals of various metals have been shown to be 100 percent, 200 percent and even as much as 300 percent harder than the same materials in bulk form. Because wear resistance often is dictated by the hardness of a metal, parts made from nanocrystals will significantly last longer than conventional parts.

Aircrafts

Researchers have made relatively awesome discoveries on nanocomposites over the last decade, ever since the pioneering work on nanocaly by the company Toyota. The dispersion of the silicate nanolayer with its high aspect ratio, large surface area, and high stiffness within a polymer matrix results in significant improvement of the properties of polymeric materials, including mechanical properties, barrier properties, resistance to solvent swelling, ablation performance, thermal stability, fire retardancy, controlled release of drugs, anisotropic electrical conductivity, and photo activity.

Layered-silicate nanocomposites have great applications, ranging from automotive and aerospace to food packaging and tissue engineering. Epoxy materials are widely used in adhesives, coatings,
composites and electronics. These are also used in designing of aircraft parts too. This epoxy system has a high glass transition temperature (Tg), good mechanical and physical performance characteristics, and low viscosity. In addition, epoxy nanocomposites as primer layer for aircraft coatings for improved anticorrosion properties are used. High performance nanocomposites are also used in fuselage sinks in aircrafts.

**Electronics**
Conductive nanocomposites are capable of conducting electric current well owing to the electric charges in their structure. Polycarbonates which is an insulator can be made conductive Polycarbonates, the inexpensive plastics known for their excellent optical and mechanical properties, could in future, find applications into newer and more important horizons. Polycarbonates are tagged as poor electrical conductors, but a research team from University of Houston (UH) has altered this very property by adding carbon nanotubes to them thereby resulting in highly conductive nanocomposites. The team has come up with a strategy to achieve higher conductivities using carbon nanotubes in plastic hosts than what has been currently achieved. By combining nanotubes with polycarbonates, the team was able to reach a milestone of creating nanocomposites with ultra-high conductive properties. Shay Curran, associate professor of physics at UH demonstrated ultra-high electrical conductive properties in these plastics by mixing them with just the right amount and type of carbon nanotubes. As a result, the inexpensive plastic used to make optical discs will feature in high-end military aircrafts to shield them against build up of electrical charges and pulses which can lead to significant failures. Additionally, by modifying the amount of carbon nanotubes added to the polycarbonate-nanotube mix, the electrical conductivity of the nanocomposite could be changed from that of silicon to a few orders below what is achieved by metals.

**Films**
The presence of filler incorporation at nano-levels has also been shown to have significant effects on the transparency and haze characteristics of films. In comparison to conventionally filled polymers, nanoclay incorporation has been shown to significantly enhance transparency and reduce haze. With polyamide based composites, this effect has been shown to be due to modifications in the crystallisation behaviour brought about by the nanoclay particles; spherulitic domain dimensions being considerably smaller. Similarly, nano-modified polymers have been shown, when employed to coat polymeric transparency materials, to enhance both toughness and hardness of these materials without interfering with light transmission characteristics.

**Environmental Protection**
Water laden atmospheres have long been regarded as one of the most damaging environments, which polymeric materials can encounter. Thus an ability to minimize the extent to which water is absorbed can be a major advantage. Available data indicate that significant reduction of water absorption in a polymer could be achieved by nanoclay incorporation. Similar effects could also be achieved with polyamide-based nanocomposites. Specifically, increasing aspect ratio diminishes substantially the amount of water absorbed, thus indicating the beneficial effects likely from nanoparticle incorporation compared to microparticle loading. Hydrophobicity enhancement would clearly promote both improved nanocomposite properties and diminish the extent to which water would be transmitted through to an underlying substrate. Thus applications in which contact with water or moist environments is likely could clearly benefit from materials incorporating nanoclay particles.

**Food Packaging**
The gaseous barrier property improvement that can result from incorporation of relatively small quantities of nanoclay materials has been shown to be substantial. Data provided from various sources indicate oxygen transmission rates for polyamide-organoclay composites, which are usually less than half of the unmodified polymer.

Further data reveals the extent to which both the amount of clay incorporated in the polymer, and the aspect ratio of the filler contributes to overall barrier performance. In particular, aspect ratio has been shown to have a major effect, with high ratios (and hence tendencies towards filler incorporation at the nano-level) quite dramatically enhancing gaseous barrier properties. Development of a combined active/passive oxygen barrier system for polyamide-6 materials is underway at various laboratories across the world. Passive barrier characteristics are provided by nanoclay particles incorporated via melt processing techniques whilst the active contribution comes from an oxygen-scavenging ingredient.

Oxygen transmission results reveal substantial benefits provided by nanoclay incorporation in comparison to the base polymer (rates approximately 15-20% of the bulk polymer value, with further benefits provided by the combined active/passive system). Increased tortuosity provided by the nanoclay particles essentially slows transmission of oxygen through the composite and drives molecules to the active scavenging species resulting in near zero oxygen transmission for a considerable period of time.

Such excellent barrier characteristics have resulted in considerable interest in nanoclay composites in food packaging applications, both flexible and rigid. Specific examples include packaging for processed meats, cheese, confectionery, cereals and boil-in-the-bag foods, also extrusion-coating applications in association with paperboard for fruit juice and dairy products, together with co-extrusion processes for the manufacture of beer and carbonated drinks bottles. The use of nanocomposite packaging would be expected to enhance considerably the shelf life of many types of food.

**Fuel Tanks**
The ability of nanoclay incorporation to reduce solvent transmission through polymers such as polyamides has been demonstrated. Available data reveals significant reductions in fuel transmission through polyamide-6/66 polymers by incorporation of nanoclay filler.

As a result, considerable interest is now being seen in these materials as both fuel tank and fuel line
components for cars. Of further interest for this type of application, the reduced fuel transmission characteristics are accompanied by significant material cost reductions. Nanocomposites are currently being used in a number of fields and new applications are being continuously developed. Other applications for nanocomposites include:

- Thin-film capacitors for computer chips
- Solid polymer electrolytes for batteries.
- Automotive engine parts and fuel tanks
- Impellers and blades
- Oxygen and gas barriers

8. CONCLUSION

Researchers have made relatively awesome discoveries over the last decade, ever since the pioneering work on nanoclay by the Toyota company. The dispersion of the silicate nanolayer with its high aspect ratio, large surface area, and high stiffness within a polymer matrix results in significant improvement of the properties of polymeric materials, including mechanical properties, barrier properties, resistance to solvent swelling, ablation performance, thermal stability, fire retardancy, controlled release of drugs, anisotropic electrical conductivity, and photo activity. Today nanocomposites are currently being used in a number of fields and new applications are being continuously developed.

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