Nanomaterials

By Brent Augustine

For centuries during the middle ages, alchemists worked wistfully to achieve the ultimate goal of creating gold or silver from other elements, but to no avail. Then rose scientific chemistry, which fostered new and rational scientific thought, while proving the blasphemy of alchemy [3]. Research and development over the next few hundred years yielded many innovative and important discoveries such as stainless steel, plastics and other polymers and even synthesized diamonds. Recently, however, scientists and engineers are becoming “new-age alchemists” by diving into a new scientific realm known as nanotechnology to create materials that will change the way we will live. Existing materials will be stronger, lighter, and more durable when coupled with nanotechnology [9]. Isolated nanoparticles exhibit amazing properties, and when mixed with other materials the new compound becomes improved in a variety of ways. There are already many nanomaterial-enhanced products on the market, and efforts are being made that would turn polymers into efficient solar energy converters simply by mixing them with nanocrystals [2]. The infinite possibilities that nanotechnology has on the production of nanomaterials is going to significantly alter the material world.

As with many new technologies, there seems to be a lack of compete understanding when it comes to how nanoparticles change the properties of materials. Nanoparticles are minute substances in the size range of 1-100 nanometers in all directions. Typically stable substances can become highly reactive and unstable when the particles become infinitesimal due to their extremely high surface to mass ratio. A series of quantum confinement effects arises that significantly change the way the particles behave such as conductivity, specific heat, increases in energy band gap, and different wave lengths of emitted light. Yet, the question remains, how can these incredible particles be applied to industry?

The phenomenonological effects these nanoparticles have when combined with existing bulk material is clear. Materials become stronger, more dent resistant, exert higher ductility, are lighter, and obtain a host of other material enhancement characteristics [9]. How these materials gain such improvements is a much more complicated matter.

The size of the nanoparticle grains strongly effect the property changes in the bulk material. For instance, the overlapping of different grain sizes affects the physical strength of the material [1]. Also, when the crystallites of a material are reduced to the nanometer scale, there is an increase in the role of interfacial defects: grain boundaries, triple junctions, and elastically distorted layers [1]. The long established Hall-Petch model, that shows the inverse relationship between grain size and material yield strength, has been proven to hold with nanoparticles as well [1]. A study of nanocrystalline Fe

$$\sigma_y = \sigma_0 + \frac{K}{\sqrt{d}}$$

Hall Petch Model:
(yield strength determined by a constant K and the mean grain size, d [5])

powder revealed that when grain size was decreased from 33nm to 8nm, hardness increased and fracture stress and elongation to failure decreased. These results can be connected to the reduction of defects in the material such as micropores and other flaws [1]. Although this has been experimentally and theoretically proven, it is still difficult to accurately predict the effects that will occur.

It is interesting to note that scientists have been using nanoparticles in tires for a very long time and never really understood why the improved effects occurred, besides that it turned the rubber black. For years, engineers have been putting carbon black nanoparticles in the rubber of tires. The results are improved strength and tensile properties, tear and abrasion resistance, and increased hardness because of the integration of carbon grains [6]. It has been found that with increased amounts of carbon black in the rubber compounds, the absolute strength initially increases because of reinforcement from the carbon grains but then decreases due to the dilution effect [6]. The improved reinforcement results by the carbon black particles can be explained by exfoliation, intercalation, dispersion, and occlusion which are essentially the interactions of the grains with the material [6].

The material properties of metals can also be improved using techniques of nanotechnology. Metals can be modified into nanocrystalline materials that consist of nanometer-sized grains with a high density of crystal-lattice defects [9]. Interestingly, these metals achieve extraordinary strength and hardness and not only maintain, but improve ductility, a unique characteristic of materials with improved hardness. Scientists believe that the nanocrystalline grains provide the strength while the tensile deformation of the material is kept intact by the embedded larger grains [9].

One particular area of research has been studying the reinforcement of polymers coupled with Polyhedral Oligomeric Silsesquioxanes (POSS) [7]. POSS is generated from a mixture of a silicon substance and water in acetone. Significant polymer material enhancement is observed when "POSS monomers are copolymerized into polymer systems [7]." The POSS nanostructures form links with the polymers in one of three ways: bead, pendant, or cross-linked formations. The names of the formations are very

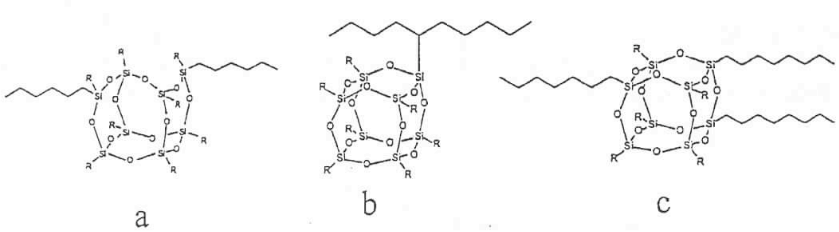

Figure 4. The most common type of POSS-polymers. (a) bead, (b) pendant and (c) cross-linked.

[7]

fitting with their physical structure; the POSS monomer splits the polymer chains in the bead type (a), has one connection to the chain in the pendant type (b), and has multiple connections in the cross-linked form (c) [7]. The connections and mixture of materials allows for greatly improved mechanicals due to the entrainment with the polymer chains by the POSS monomers [7]. A unique feature of the POSS nanostructured chemicals is that there are over 120 monomers available which makes compatibility with specific polymer matrices very probable [7].

The previous examples were just a few of the many types of molecularly reinforced materials by nanoparticles. It provides a brief glimpse at how such material enhancements work. The layperson is not so concerned with the question of how, he/she just wants product results. The majorities of people are able to notice product improvements but are oblivious to the reasons why things are becoming more reliable. Nanomaterials show up all over the market in several different industries. The carbon black rubber filler in tires is already a $4 billion industry. Nanocomposites line the bed of GM's new Hummer H2 to provide more strength and dent resistance [3]. Wilson® has incorporated nanotechnology with tennis by adding nano-sized silicon dioxide crystals to rackets to increase their power [3]. Wilson also coated tennis balls with a butyl-based nanoparticle that cuts air permeation in half as well as makes them last longer [4]. Golf balls have also been "nanoteched" to improve durability, make them fly straighter, and decrease that nasty slice that we all enjoy. One of the most interesting applications of nanoparticles in materials is the application of nanocrystals as light converters in solar cells.

Although it remains experimental, recent evidence suggests that soon there will be solar converting photocells that are vastly more efficient than current solar energy systems. Existing solar cells are being improved by the addition of silicon nanocrystals [7]. However, more exciting processes involve using particles such as copper based nanocrystals and embedding them in polymers [2]. The unique properties of the nanocrystals allow them to convert not only solar photons but also infrared light and phonons. The added receptivity of the particles to forms of energy makes the technology very desirable as an energy source. One of the most promising nanocrystals used in photovoltaic applications is copper indium diselenide because of its high absorption coefficient, suitable low band gap, and radiation stability [2]. When exposed to photons, the free charges of the particles are generated and transported along the polymer, due to the effective charge separation of the nanocrystals, to electrodes. The effectiveness of the charge collection depends on the ability of the carriers to arrive at the electrodes without recombining with oppositely charged particles [2]. The process is far from being perfected, but the possibilities are blossoming.

Consumers will most certainly continue to experience a relatively high degree of technological somnambulism, or "sleep walking," when it comes to nanomaterials. They will have little clue that the decrease in blown tires, the improved power in their forehand shot, or the dent resistant car beds are attributed to nanotechnology. Efficient and productive solar converting polymers will certainly garner more attention than the previous examples have, but it will take time before serious production is seen. Before the infinite number of applications of nanomaterials is discovered, a clear understanding of how nano-enhanced materials work, act, respond to stimuli, and perform under all situations is vital. It will be interesting to see what amazing materials the "new-age alchemists" can create.

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