The Effect of Metal Oxide on Nanoparticles from Thermite Reactions

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Abstract

The purpose of this research was to determine how metal oxide used in a thermite reaction can impact the production of nanoparticles. The results showed the presence of nanoparticles (less than 1 micron in diameter) of at least one type produced by each metal oxide. The typical particles were metallic spheres, which ranged from 300 nanometers in diameter to as large as 20000 nanometers in diameter. The smallest spheres were iron, whereas the largest were manganese. The most interesting result was the formation of manganese oxide nanotubes. This research may provide reason to further investigate the use of thermite reactions in nanoparticle production.

Introduction

The purpose of this research was to investigate the production of nanoparticles formed as a result of a thermite reaction. The goal of this research was to determine what types of nanoparticles could be produced utilizing thermite reactions with different metal oxides. Current methods of producing metallic nanoparticles are extremely expensive, such as by injecting molten metal into an inert atmosphere at high pressure. Therefore, the rationale for this project was to determine if nanoparticles could be produced in a cheap and efficient manner utilizing thermite reactions.

A thermite reaction is defined as a highly exothermic oxidation reduction reaction between a metallic oxide and aluminum powder. The most common form of thermite uses iron (III) oxide and has been used since the before the start of the twentieth century in applications such as welding. The reaction for iron oxide thermite follows: $Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(l) + Al_2O_3 + heat$. Thermite mixtures are safe and are difficult to initiate by accident due to the fact that they require heat of several hundred degrees Celsius for the reaction to be initiated. Ignition is often performed by using a magnesium fuse or a chemical reaction to provide the energy required to initiate the reaction, such as potassium permanganate hypergol.

Recent attention to nanotechnology has given new focus to thermite reactions. The intense heat reached during the reaction is capable of creating several forms of nanoparticles. The most common nanoparticles produced with thermite reactions are carbon nanotubes which are formed when a small amount of carbon is added to the thermite mixture, usually in the form of graphite. A recent discovery has pointed to the fact that thermite reactions can be used to produce hollow metallic spheres that are only nanometers in diameter. These have many potential applications, one of which is for producing hydrogen gas for fuel cells by reacting the nanoparticles with an acid. Another application of the nanoparticles is nanofiltration which uses the small particles to filter out toxics that may be found in water. Yet another potential application is to use nanoparticles in new propellants, such as rocket fuel, because their small size allows for them to be consumed more rapidly and release more energy.

There have also been military uses of thermite, including thermite grenades and incendiary bombs (Cheetham, 2003.) Because the thermite mixture consists of a fuel (Al) and an oxidizer (metal oxide) a thermite mixture can burn under almost any conditions. Also, because the reaction results in pure metal from the oxide, it has been used to purify various metals for many uses, including purifying uranium metal from uranium oxide.

The recent National Nanotechnology Initiative expects an increase in the funding for research and development of nanotechnology to reach over

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1 billion dollars, due to the plethora of applications nanotechnology can have for society. Nanotechnology can provide major economic, environmental, military, and medical benefits. In the near future, nanotechnology may decrease the size of a modern PC to a pocket sized appliance, or even smaller (National Nanotechnology Initiative, 2005.) There has been some research into using metallic nanoparticles as a replacement for expensive catalysts in several organic reactions that currently require the catalytic action of a noble metal which may also be harmful to the environment (Chin, 2002). Iron nanoparticles are being investigated for various reasons including their special magnetic and electrical properties. The unique properties exhibited by nanoparticles have led many researchers to look at nanosized composites that will allow for potential superconductors at the nano level (Sudakar and Kutty, 2004). More exotic thermite mixtures are being tested to produce new alloys and composite materials. These are often produced as nanoparticles, which possess many new desired properties. Ni3Si has been combined with Cr through the utilization of thermite reactions. The resulting material has tremendous strength and could prove useful in building materials (Bi et al., 2005). Nanoscale composites are one of the most extensively researched nano materials. This is because of the importance they have in reducing the size of computers, while increasing the power. Even the electrical connections are being influenced by nanotechnology. Research is being performed on new soldering compositions using silver nanoparticles because they have a higher density and thus less electrical resistance (Moon et al., 2005).

The research hypothesis for this project was that all metal oxides tested would produce nanoparticles of various types as a result of thermite reactions. The null hypothesis was that all metal oxides tested would not produce any nanoparticles.

Materials and Methods

The materials needed for this research project were ferric oxide powder, cupric oxide powder, manganese (IV) oxide powder, aluminum powder, and magnesium ribbon. The metal oxide was combined with the aluminum powder in proportions based on proportions found during alpha testing. The ratios were: Fe_2O_3:Al 3:8, CuO: Al 3:2, MnO_2:Al 1:1. Twenty grams of each mixture were added to a container made from aluminum foil in the top of a crucible and then placed in a large beaker filled with sand. A strip of magnesium ribbon was then placed in the mixture, and the beaker was set inside a fume hood. A butane lighter was used to light the magnesium and initiate the reaction. The resulting metal was collected by washing the crucible with methanol. Next the slurry of metal and methanol was triple filtered allowing the smallest particles to remain suspended in methanol until they could be analyzed with the electron microscope, reducing the possibility of oxidation of the samples. The methanol was evaporated and the solid particles were collected and placed on carbon tape. The samples were then loaded into the LEO 440 scanning electron microscope and any particles found were recorded by the computer. The size of the particles was measured using the software included with the electron microscope.

Results

Table 1: Nanoparticle size, type, diameter, number found and range

Particle Type	Material	average diameter	number found	size range
sphere	Manganese Metal	9416.67nm	6	3000-20000nm
tube	Manganese Oxide	909 nm	too many to count	na
sphere	Iron Metal	918.86 nm	35	800-3000 nm
hollow sphere	Iron Metal	2000 nm	1	2000 nm
sphere	Copper Metal	1401.11 nm	9	330-4500 nm

Table 1 shows the particle statistics from the electron microscope results. These include the chemical composition, and the average diameter and the number of particles found. It is very likely that there were many particles missed during the electron microscope analysis.

Image 1: Cluster of Manganese Oxide Nanotube

This is an image of manganese oxide nanotubes found using the electron microscope. The nanotubes were the most interesting particles found in the analysis, and only one example of a manganese oxide nanotube cluster was found. The other particles were spherical in nature.

Discussion and Conclusion

The results show a variety of sizes on particles formed by the thermite reactions. These range from small solid and hollow metallic spheres to clusters of nanotubes. Based on the reaction times, ferric oxide is the most vigorous reaction, but produces a higher temperature; whereas cupric oxide thermite was the most explosive but had the lowest temperature. Based on the classification size for a true nanoparticle, the results obtained show that there were in fact metallic nanospheres produced by the reaction. The smallest spherical particles that can be classified as nanoparticles were produced in the cupric oxide reaction, and in the ferric oxide thermite reaction. In the manganese dioxide reaction, there were no metallic nanospheres produced; however a large cluster of manganese oxide nanotubes was found. The hypothesis was if various oxides were tested, then nanoparticles would be produced. The research hypothesis was supported by the variety of particles that was found. Due to the nature of the research, there was no statistical analysis used to determine significance. The results are similar to previous research.

Limitations

Some bias included the time between the reactions and the analysis with the electron microscope, which allowed for significant oxidation of the samples. Because the separation technique was unproven, other particles may have been lost while filtering, evaporating, or transferring samples. Another source of error may have been that the limitations of the electron microscope prevented accurate detection of other particles.

Future project could be improved in a variety of ways. These include testing more metal oxides, different atmospheres for the reactions, different ratios of reactants, and using a more reliable separation technique, a higher resolution electron microscope, and faster access to an electron microscope for analysis.

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