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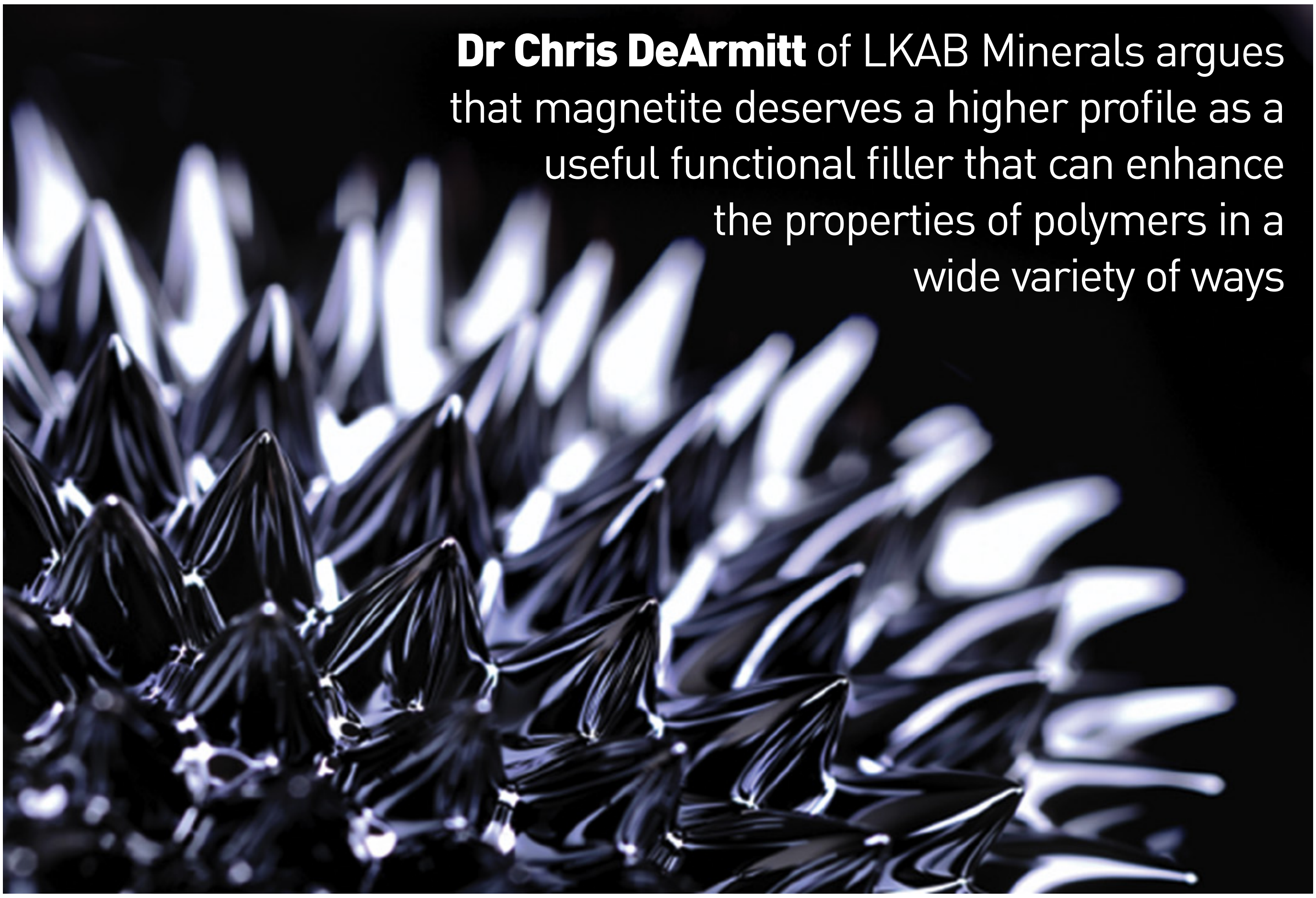

Dr Chris DeArmitt of LKAB Minerals argues that magnetite deserves a higher profile as a useful functional filler that can enhance the properties of polymers in a wide variety of ways

Magnetite: exploring the multi-functional filler

Magnetite is probably the most interesting and useful filler you've never heard of. As with all materials, its applications stem from its properties. So, what are the most noteworthy properties of magnetite?

It has a high density of 5.2 g/cm^3, and it is a hard material with a Mohs hardness of around 6. Magnetite is both electrically and thermally conductive, plus it has an unusually high specific heat capacity. The black, lustrous mineral is also extremely pure and inert.

This article will take a look at each of these properties in turn and see how they lead to real-world applications for this specialty mineral filler.

Increasing density

Density is perhaps not the most glamorous of properties, but there are many applications requiring a dense filler. These vary from counterweights for washing machines to ballast and bowling balls.

Traditionally, barium sulphate has filled the role of high density filler – it has a density of 4-4.5 g/cm^3. However, over the past decade, magnetite has become more popular as it has a higher density of 5.2 g/cm^3 and is therefore more effective. In some applications, adding mass is the sole goal, but sometimes other benefits are in focus. For example, adding heft creates the perception of a high-quality product. As a result, magnetite is used in cosmetics packaging, synthetic leather and household appliances to add luxury feel (haptics). Compound densities up to 3.0 g/cm^3 are attainable using magnetite.

Dense fillers can also be used for sound and vibration damping. Typically, high levels of a dense filler – up to around 80% by weight – are added to a soft, high-loss polymer that deforms by non-elastic/viscous flow. Magnetite has been used by major automotive companies for decades in injection moulded parts, for example in PA or PP, and as soft sheets to isolate the cabin from road noise, or in strategically placed polyurethane spray foam.

When dispersed in oil, Magnetite forms a ferro-fluid or magneto-rheological fluid

Table 1: Using magnetite is effective way to increase the density of a polymer compound

Mineral	Weight (%)	Volume (%)	Density (g/cm³)	Density Increase (%)
$CaCO_3$	40	18.2	1.23	37
Talc	40	18.2	1.23	37
Magnetite	40	10.3	1.34	49
$CaCO_3$	68	41	1.64	82
Talc	68	41	1.64	82
Magnetite	80	41	2.66	196

Blocking radiation

Magnetite can also be used as a radiation blocking filler in plastics. Unusually, it blocks several different types of radiation including x-rays, gamma rays, microwaves, and radar. Magnetite is able to block so many types of radiation because of its unique combination of several disparate properties. For example, blocking x-rays or gamma rays relies on density; the higher, the better.

Magnetite has been used for decades as aggregate in concrete for the radiology units of hospitals where magnetite aggregate allows walls to be made 40% thinner compared to standard concrete while still providing effective blocking. So, using it to do the same thing in plastic is a natural progression.

The unusual microwave and radar blocking efficacy does not rely on density but on a totally different property, namely electrical conductivity. Materials with very high or low electrical conductivity do not absorb microwaves. Highly conductive materials such as metals reflect microwaves. Good insulators, like plastics, allow microwaves to pass straight through unimpeded. For effective blocking by absorption, one needs an intermediate level of electrical conductivity. Magnetite, classified as a semi-metal with a band-gap of just 0.1 eV has just the right level of electrical conductivity to provide outstanding absorption. Which brings us to the next topic...

Magnetite processing at LKAB Minerals

Microwave and induction heating

A study by the US Department of the Interior showed that magnetite heated quickest of 160 materials tested in a microwave oven. Other researchers wondered why magnetite is so very effective at adsorbing microwaves and converting that energy to heat. They performed a detailed study and discovered the reason.

Microwaves, like other forms of electromagnetic radiation, consist of an electric and a magnetic component. Uniquely, magnetite has a combination of moderate electrical conductivity plus magnetic properties so is able to absorb both the electric and magnetic components of the electromagnetic energy.

One of the oldest applications is foot warmers where magnetite filled elastomer is used as an insole. Just 30 seconds in the microwave heats the insole due to the microwave susceptibility provided by the magnetite. In addition, the exceptionally high specific heat capacity of magnetite means more heat can be stored and then released to ensure warm feet.

A newer application is in pot-hole repair. In colder climates, it is difficult to achieve satisfactory results using conventional repair technology because the warm bitumen cools too quickly so that proper wetting and adhesion to the road is not possible. It has been demonstrated that adding magnetite to the pot-hole repair compound allows it to be microwave heated in-situ. This allows the entire area to get warm which in turn provides better adhesion and extends the durability of the repair.

Future developments are expected to include magnetite in plastic cookware. This would allow induction heatable plastic cookware, speed up heating in microwave ovens and also help heat transfer when cooking in conventional ovens.

Magnetic attractions

Magnetite is known for and named after, its magnetic properties. As a ferri-magnetic material, it is not actually magnetic itself, but it is attracted to a magnet. This effect is exploited in many applications.

For example, magnetite paint is used in the home or office to allow magnets to stick to the wall. Surprisingly, although magnetite is black, its pigmenting strength is low, so it is still possible to colour such paints by adding pigment or dye.

Magnetite can be added as a tracer to plastics to make the material detectable. This is useful in the food processing industry when one needs to be able to find and remove any plastic contaminants that may have

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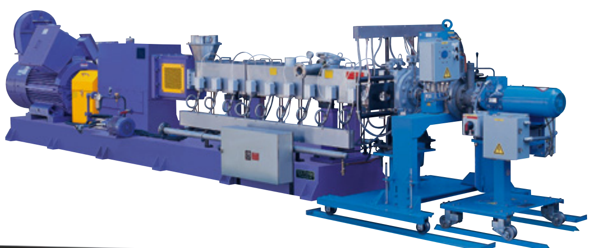

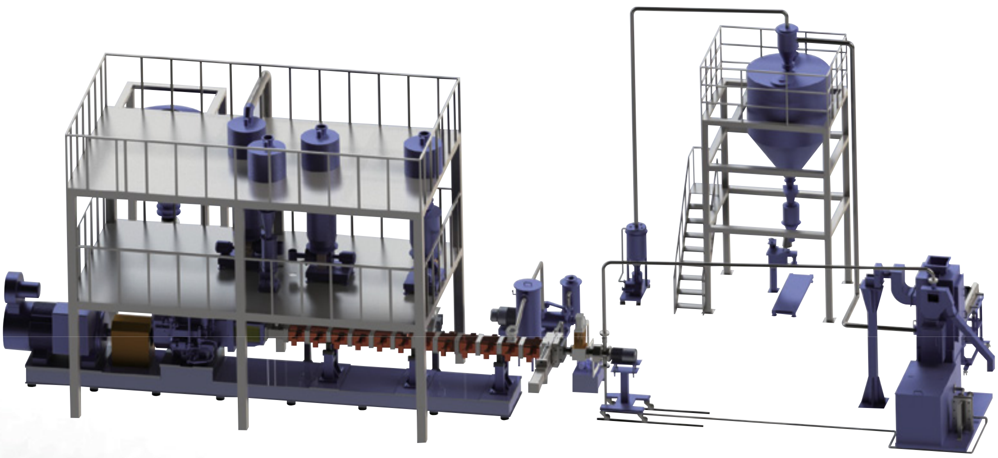

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Table 2: Properties of magnetite compared to common fillers such as calcium carbonate and talc

Property	Typical mineral filler	Magnetite
Colour	White	Black
Density	2.5-3.0 g/cm^3	5.2 g/cm^3
Mohs hardness	2-3	5.5-6
Attraction to a magnet	No	Yes
Electrical conductivity	Insulator	Conductive
Chemical composition	Carbonates and silicates	Oxide
Volumetric heat capacity	2.1 kJ L^{-1} K^{-1}	3.8 kJ L^{-1} K^{-1}
Microwave heatable	No	Yes
Radiation blocking	No	Yes

found their way into the food from processing machinery, for example. Of course, the magnetite would need to be safe for food contact and grades are indeed available with such high purity that they pass US and EU regulations for use in food contact plastics.

Adding magnetite helps in production as well. One example is floor mats for automobiles where the increased density adds vibration damping, while the material's magnetic properties allow robots to lift and place the mats accurately.

Magnetic putty is sold as a novelty item providing a fun way to experience the properties of magnetite.

One well known use of magnetite is in ferro-fluids and magneto-rheological fluids which respond to a magnetic field. These are used in loudspeakers where the magnetic field holds the fluid in place and the high thermal conductivity of the magnetite helps keep the voice coils cool.

They are also used to form magnetic seals for pumps, gearboxes, motors and even submarine shafts. Such seals are particularly useful for shafts that are not round where normal mechanical seals do not perform well. Such fluid was first made by NASA where natural magnetite was ground very fine in oil with dispersant added. Nowadays, such fluids are made using synthetic magnetite prepared by a precipitation reaction.

Electrical and thermal conductivity

Pure magnetite has marked electrical conductivity and it is classed as a half-metal due to its low band gap. Resistivity is just ~1.0 x 10^4 mΩ cm, which opens up new possibilities for conductive plastic formulations. This has been reported in several polymer types including PP and PA 6 where resistivities as low as 10 kΩ.m were achieved when the loading was 47 volume %. Applications include EMI blocking and as a permanent, non-migrating, anti-static material. Once magnetite has rendered the plastic conductive, it is then possible to electroplate metals on the surface to make decorative coatings.

The thermal conductivity of magnetite is 5.1 W m^{-1} K^{-1}, which is much higher than other mineral fillers such as glass fibre or barium sulphate. Common plastics have low thermal conductivity, in the range of 0.2-0.4 W m^{-1} K^{-1}. This can be increased by adding fillers with magnetite being particularly effective giving composites with values as high as 1 W m^{-1} K^{-1}.

Thermally conductive plastics are sought after for heat management in electronic devices. Magnetite filled plastics are also used in luxury products such as perfume bottle caps where the magnetite serves multiple roles. It adds heft for a high quality feel and the thermal conductivity provides an "organic" feel that designers appreciate. The high thermal conductivity has been shown to significantly decrease cycle time when moulding parts, thus giving higher productivity. Furthermore, the even distribution of heat prevents hot spots and degradation.

Another important thermal property is the heat capacity, which is the amount of heat required to heat up a material and the amount of heat it can store. Magnetite is used as a "battery" for heat. It can be charged up and then release the heat over an extended period of time. Thus, it has been used for decades in night storage heaters and saunas. In recent years there has been a lot of focus on energy efficient houses. The remarkably high heat capacity of magnetite makes it ideal for buffering temperature fluctuations in buildings, thereby lowering the heating and cooling costs. It turns out that the heat capacity per unit volume of virtually every solid is the same, so the only way to achieve higher heat storage is magnetite, which has a value some 70% higher than other materials.

Optical properties and safety

One glance will tell you that magnetite is black. However, there is more to it than that. Natural magnetite fractures during milling to form angular particles. Coarser grades in particular have a metallic sheen and are added to plastics as a form of decoration. One example is in solid surfaces such as kitchen counter tops. The magnetite particles are embedded in an acrylic matrix and confer a black granite-like appearance.

One would assume that magnetite filled plastics would come in any colour you want as long as it's black. Surprisingly, it turns out that plastics filled with natural magnetite can be coloured over a wide palette of colours by adding dye or pigment. The reason is that magnetite has low tinting strength, i.e. it is a weak pigment. Coarser grades of magnetite are especially suitable for making coloured plastic materials.

With regard to material safety, magnetite is present in the cells of organisms and animals including humans.

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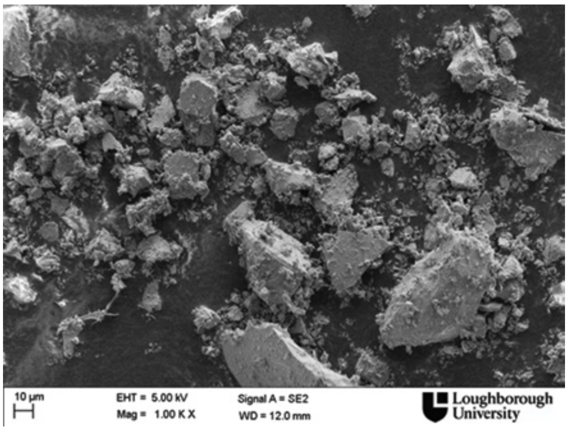

SEM image of LKAB Minerals' MagniF 10 high-purity natural magnetite

Magnetite is generally recognized as safe (GRAS). Like other natural minerals, it is TSCA listed and REACH exempted by definition. LKAB Minerals supply natural magnetite grades with such purity that they comply with FDA standards for use in food contact plastics.

Types and sources of magnetite

Nanoparticulate magnetite is a synthetic material used for specialty applications such as magnetic fluids, but not normally used in plastics. Nanoparticles lead to high viscosity so only low loadings can be used. Nano-magnetite also has poor thermal stability making it unsuited to typical polymer processing methods.

Natural magnetite is far more stable and much better suited for polymer use, but was slow to develop because the market requires high purity and a very finely ground material. Some decades ago, Minelco, now known as LKAB Minerals, set out to create filler grades and then to identify applications for the newly created specialty filler. That journey has been an interesting one culminating in many and diverse uses, several of which have been mentioned in this article. The list continues to grow year by year as people learn of the filler and how it can bring their products to the next level of performance.

Just as magnetite compasses helped ancient sailors to find the New World, magnetite is still helping pioneers to create a new world of materials and applications.

About the author

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