DESIGNING FOR SAFE DEMOLITION – THE HAZARD POTENTIAL OF NANOMATERIALS

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When specifying products, designers should consider the health and safety of those working with the materials, either during construction or during decommissioning and demolition of a building or facility at the end of its life. The use of nanomaterials (those with at least one dimension less than 100 nm) in construction is reported to be on the increase, but it is difficult to identify exactly which products contain them; and there are uncertainties regarding their hazard potential. This paper is based on an ongoing IOSH-sponsored study to catalogue nano-enabled construction products through review of the literature, and consideration of manufacturers' data; and interviews with construction professionals to assess how widely they are used. The study is also using material characterisation techniques to identify the nanomaterials involved and assess the potential for particle release from products at end of life. The study has found wide variation in the hazard profiles of the different materials and products currently available. Some specialist concretes for example, are enhanced with silica fume which has been widely used for around 40 years and is a relatively low-risk nanomaterial. Other forms of nanosilica are used in insulation materials and surface coatings. Carbon nanotubes (CNT) are a nanomaterial which are hazardous in some forms. CNTs are not yet used commercially in concrete but are forecast to appear in the marketplace in a limited capacity by 2016. They are also used in very specialised surface coatings. Further information is needed to assess whether they could pose a health risk at end-of life from the combined impacts of material degradation over time and the destructive techniques commonly applied in building demolition and recycling (e.g. crushing, cutting, drilling etc).

Keywords: nanotechnology, silica, CNT, health risk, demolition.

INTRODUCTION

Nanomaterials generally have either particles or internal structures (e.g. holes or pores) with dimensions between 1 and 100 nanometres (nm). They can have very different properties from the more common ‘bulk’ forms of materials which are chemically similar. They are not all new – for example, carbon black is a nanomaterial which has been used as a rubber reinforcer in tyres for around 100 years. However, there has been a proliferation in the use of nanotechnology in recent years with the discovery of completely new forms of materials alongside the gradual evolution of familiar substances. Some of these have the potential to provide significant societal benefits, for example the use of nanomaterials to remove chlorinated hydrocarbons from contaminated land (Mueller et al. 2012); or in healthcare to allow targeted treatments for diseases such as cancer and multiple sclerosis. Other applications are arguably more trivial such as the use of nanosilver in socks, hairdryers and washing machines to ‘sterilise and deodorise (Samsung website). Construction is also seeing an expansion in the use of nanomaterials, with some predicting that 50% of building products will be nano-enabled by 2025 (AECOM 2014).

Concerns have been raised about the hazard potential of nanomaterials. In principle, the toxicity of small particles is generally higher than that of larger particles with the same physicochemical properties, as a consequence of their greater surface area and higher reactivity (Lim et al. 2012). However, many other characteristics of materials also affect their hazardousness: including their shape, how strongly the particles adhere together, and the presence of additional substances such as heavy metals. For example, there are particular concerns regarding substances with high aspect ratios – those which are long and thin and might therefore behave in ways similar to asbestos fibres (Donaldson et al. 2013); this could include some types of carbon nanotubes (CNTs).

There is a lack of clarity regarding the extent to which construction products currently contain nanomaterials, and which particular material(s) might be present. This paper is based on an ongoing research project funded by the Institution of Occupational Safety and Health (IOSH) to address these uncertainties. A particular area of concern is the potential for exposure to nanoparticles at demolition, given the destructive and sometimes explosive nature of methods used. The research involves:

- A desktop study of the literature and manufacturers' data to identify construction products which might contain nanomaterials. This is being supplemented with e mail exchanges and interviews with representatives of companies which make and sell these products; and interviews with construction industry professionals to assess the extent and scope of their use.
- Laboratory based testing of a selection of construction products to identify the particular nanomaterials which they contain; followed by destructive testing to mimic common demolition methods and assess the potential for particle release.

An early finding of the work has been the variation in the hazard profiles of different nanomaterials. This paper uses selected findings from the research to illustrate this by comparing two nanomaterials which are commonly identified in the literature as being relevant to construction – silica (silicon dioxide) and Carbon Nanotubes (CNTs). In each case, the nanomaterial and its likely construction uses will be described and then the hazard potential considered. By highlighting the similarities and differences between the two materials, the paper will illustrate the importance of gaining a deeper understanding of building materials, beyond simply whether or not they are 'nano'.

SILICA

Nano forms of silica are found in various products which are widely accessible for use in the built environment, being available to both industry professionals and home owners. They are industrially produced with a wide range of particle sizes and associated properties; some forms are a by-product of silicon production, and applications have developed to take advantage of this. The structure of nanosilica is predominantly amorphous (literally, without a clear shape or form), and differs from the more hazardous crystalline silica (e.g. quartz) which is commonly used in construction and is a key constituent of Portland cement. Typical uses for nanosilicas in construction include concrete, insulation and surface coatings.

Silica in concrete

Microsilica (also known as silica fume) has an average particle size of around 150 nm, but is classed as a nanomaterial because over 50% of its particles by number are smaller than 100 nm. The small spherical particles enable concrete to be produced which is strong, dense and durable, with improved plasticity and reduced porosity (Friede 2006). It can be easily pumped long distances, and can be self-levelling. Most of the major concrete producers include microsilica-enabled concretes in their portfolio, and these have been in use for around

40 years. They are most likely to be used in complex or prestigious buildings - interviews with industry professionals suggest that microsilica concretes account for a relatively small proportion of the concrete market in the UK, largely because there are other additives, which are cheaper or easier to use, which provide similar properties (Goodier et al. 2015).

A second silica additive which can be used in concrete is nanosilica (also known, confusingly, as fumed silica). This has a particle size about 10 times smaller than silica fume and can be used to make ultra-high performance concretes (UHPC) which are very dense and allow the production of thin, strong concrete slabs and elements (Schmidt et al. 2013).

Silica in insulation

Silica insulation materials use aerogels which have been described as “the most effective thermal insulation on earth” (Aspen Aerogel website). They are formed by replacing the liquid in a silica gel with air, leaving a material which is around 97% air in a silica framework. The excellent insulating properties of the materials arise from the poor conductivity of air, in addition to the improved resistance to heat flow which is associated with decreasing pore size i.e. the very small spaces within the silica structure (Hanus & Harris 2013). Aerogels are commonly described in manufacturers’ and academic literature as being ‘nanoporous’ (van Broekhuizen & Van Broekhuizen 2009) or ‘nanostructured’ and as not containing nanoparticles. Notwithstanding, a small number of nanoparticles were seen in insulation materials tested in the current research.

Aerogels are used in three main forms of insulation. The first are translucent granules which can be included within walls or ceiling materials designed to allow daylight entry. The second are blankets which include the aerogel in a fibre matrix to produce a durable and flexible material which has additional benefits of providing noise insulation and fire retardancy. These blankets can then be wrapped around pipes and other structures or applied to plasterboard to create thermal panels. The third insulation type is Vacuum Insulated Panels, which use impermeable laminates to enclose silica aerogel within a vacuum. All these materials are relatively expensive (perhaps 6-10 times the more commonly used equivalents (Cuce et al. 2014)) and are currently used predominantly in specialist applications such as oil rigs or arctic modules.

Silica in coatings

Nano-enabled coatings are widely available to the building trade or the home consumer, offering waterproofing or dirt resistance (generally as a result of super-hydrophobic properties), as well as increased scratch resistance. Figure 1, taken with a scanning electron microscope as part of the current research, shows the structure of one such material. This product, which is marketed for use in shower enclosures, is reported to have water and oil-repellent properties and to be easy to keep clean and to reduce lime scale build-up. Nanosilica is one of a number of materials which contribute to these products (others include titanium, silver and aluminium) but identifying exactly which materials are contained and whether they are at the nanoscale is extremely difficult. The presence of nanomaterials is rarely identified in material safety data sheets, and some materials are marketed as nanotechnology but do not actually contain nanoparticles (see for example, Figure 2).

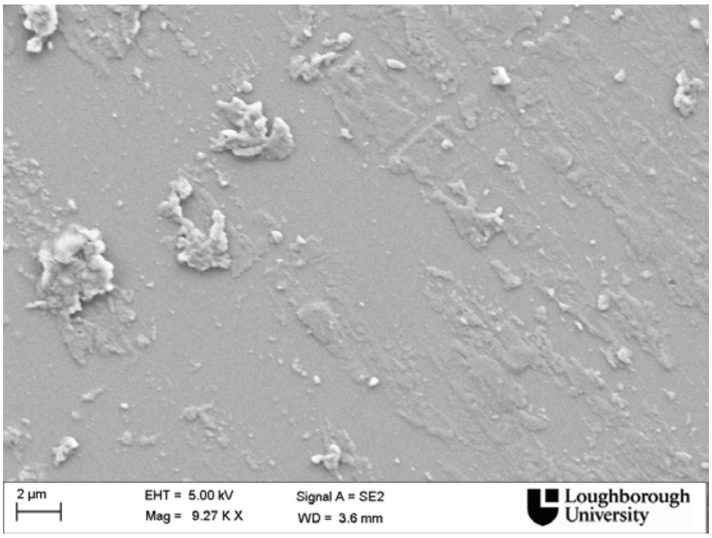

Figure 1 A sample of coated glass, showing a small number of nanosized particles

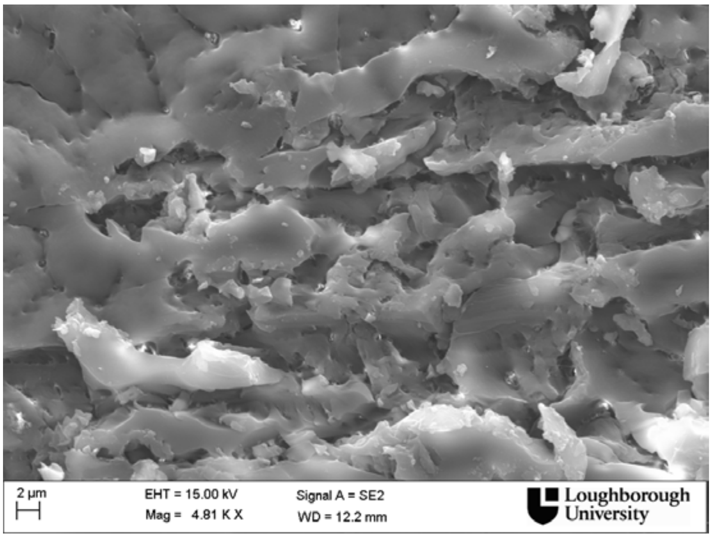

Figure 2 A 'nanotechnology coating', which does not actually contain nanoparticles

Hazard potential of nanosilica at demolition

Nanosilica (including silica fume) is generally identified as being at the safer end of the nanospectrum (Som et al 2014; Becker 2011). A detailed review by Napierska et al (2010) concludes that there is insufficient evidence to declare it ‘safe’, but also identifies that any effects on the lungs appear to be reversible (i.e. temporary). It is important to reiterate that the nanosilica used in building materials is generally amorphous in structure; this is a material which in its non-nano form is markedly less hazardous than the crystalline silica (quartz) found in Portland cement which contributes to silicosis and other long-term lung diseases.

Common demolition and recycling methods used for concrete include crushing, breaking or exploding structures (see Figure 3), these are processes which are recognised in the industry as having a high potential for dust release. Exposure to dust from insulation materials might occur if they are removed manually, in readiness for transfer to landfill. Exposure from coatings will depend on the substrate – wood removed from buildings is generally either chopped mechanically for fuel or transported to landfill; concrete structures will be treated by the usual demolition methods regardless of the presence of coatings. There is therefore some potential for dust exposure to occur with all materials.

(source:DSM demolition)

(source: Jones, Loughborough University)

Figure 3 Stages of concrete demolition and recycling with the potential to cause dust release

Testing in this research to quantify nanosilica content has found that relatively small numbers of nanoparticles are present in either insulation materials or surface coatings. This is also the case for cured concrete (Figure 4), although further testing is needed to confirm this with certainty.

In fact, nanoparticles are released during the demolition of concrete, regardless of whether these have been intentionally added. A high proportion of the particles released by the destruction of standard (non-nano) concrete are reported to be nano-sized (Kumar & Morawska 2014), known as Process Generated Nanoparticles. It is not yet known whether this significantly increases if nanomaterials are added during construction, although if the number of added nanoparticles is small this may not increase particle release substantially. Regardless of whether nanomaterials are believed to be present, good practice in demolition should always take into account the risk of dust exposure, with control measures including the use of water to reduce dust and the use of appropriate, properly fitted PPE. It is commonly recommended (e.g. by the HSE in the UK) that an FFP3 mask (N95 in the US) is used to protect against construction dust, such masks typically provide protection against both large particles and nanosized ones (Schaffer 2009).

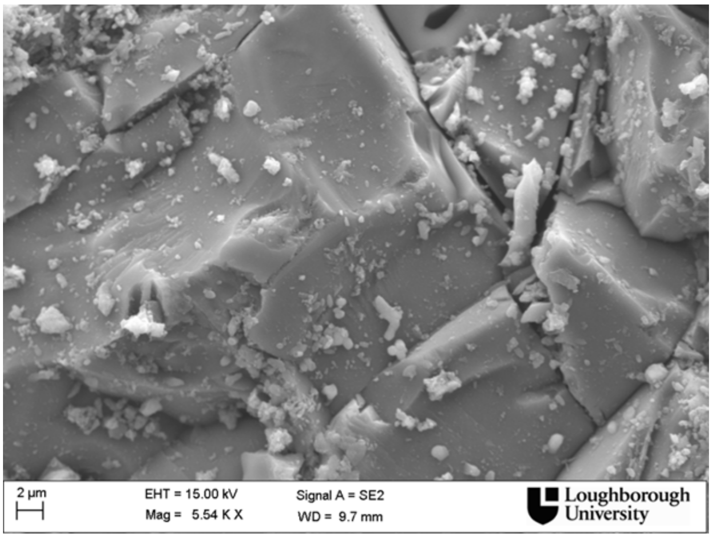

Figure 4 Silica fume concrete, showing a small number of nanoparticles (taken from Jones et al 2014, in press)

CARBON NANOTUBES

Carbon nanotubes (CNTs) are hollow structures with a diameter between 1 and 100 nm, and a length of several microns or longer. They essentially consist of a single atom layer of carbon (graphene) rolled into a tube, and may have a single wall (SWCNT), or may consist of several tubes inside each other, multi-walled carbon nano tubes (MWCNT). They are potentially useful in construction and in many other applications because of their extremely high strength and their electrical conductivity. They are currently, however, expensive to produce and difficult to work with. For example, they have a strong tendency to agglomerate and aggregate, requiring complex techniques to disperse them within materials to take advantage of their functionality. Interviewees for the current research considered the technology to be some way from commercial use in construction. Nevertheless, production capacity for CNT is rapidly increasing and prices falling, so that developments may occur quickly once suitable processes and opportunities are developed.

CNTs in Concrete

CNTs are widely discussed within the academic literature as a potential additive for concrete. In particular, they are reported to provide high strength, so that some concrete structures might eventually be built without steel reinforcement. They might also provide self-healing properties, or have the ability to resist crack propagation (although other materials can also provide these properties); and potentially can be ‘self-sensing’, enabling damage detection at an early stage.

Concretes containing CNTS are not commercially available currently but a recent report by Eden Energy (2014) has announced “[a] preliminary trial in USA ……of Eden’s CNT enriched concrete on a suitable roadway or similar area”, is scheduled to take place in late 2014/2015.

CNTs in Coatings

At least one company is marketing a coating for steel based on CNTs which offers 'significant advantages' in corrosion protection (Tesla website). Others are marketing CNTs for inclusion in paints which offer resistance against fire or provide non-stick qualities for use in marine environments such as on boats or oil rigs. It is very difficult to identify how much such materials are being used or even whether they have moved beyond development and trial phases.

Hazard potential of CNTs at demolition

The main concerns regarding the health risks of CNTs arise from their similarity in structure to asbestos (i.e. needle shape, high aspect ratio); their length, diameter and bio persistence influence their toxicity. It is commonly accepted that fibres narrower than 1μm are respirable and are carried to the lower parts of the lungs - this will include all CNTs (which have diameters as low as 1 nm). Fibres longer than 5 μm are considered potentially harmful as they either become lodged in the pleural space; or are too long for cells to break down and discharge, and hence become embedded in the lung tissue. Shorter, tangled CNTs are less harmful as they are more easily expelled by the usual mechanisms (Donaldson et al. 2013). However, some studies have identified that shorter fibres (for example, less than 2 μm) can also have adverse effects, and there is also a lack of agreement on the diameter of CNTs which are the most problematic (Madani et al. 2013). Additional factors such as the presence of heavy metals or the extent to which CNTs are aggregated together are similarly reported to affect toxicity. There is, therefore, still a degree of uncertainty around the hazardousness of CNTs and wide variation depending on the characteristics of the specific material used.

Exposure potential at demolition will, as for nanosilica, be from crushing, breaking, and possibly explosive techniques. For coatings, exposure will depend on the substrate to which it is applied – metals, for example, are likely to be cut up using mechanical or heat based tools prior to smelting for reuse.

One way of reducing the hazard from CNTs is by encasing them within a carrier substance or matrix, so that they are less likely to become airborne, and potentially less likely to be toxic. For example, Eden Energy, who are developing CNT-enhanced concrete as mentioned above, report that they have addressed health and safety concerns through the inclusion of the CNTs in a liquid admixture, and the fact that it will be firmly bonded to the finished concrete. The robustness of such protective matrices will clearly influence the health risk from nanomaterials at the end of life of the structure. There is some evidence that a combination of weathering over time (for example by UV light, which degrades some polymers) and mechanical stress (which is likely to occur at several stages of demolition and recycling) can result in CNTs being released (Hirth et al. 2013). Testing to assess the likelihood of this occurring needs to be done on real products as there is likely to be significant variation between different types of matrix (in addition to the variation in hazard related to different types of CNT). However, this is difficult to do in advance of products being commercially released unless developers choose to carry out or collaborate with such testing.

CONCLUSION

Nanotechnology can be of considerable benefit to the construction industry and the built environment– nanosilicas and CNTs both have much to offer, as do nanoforms of other materials such as titanium dioxide, silver and zinc. However, there are also possible health risks: these vary between different substances, and with different forms of each substance. There is a lack of transparency regarding the use of nanomaterials which makes it difficult to identify where they are used and in what forms. This is a universal issue, applying to the two materials discussed in this paper as well as to other nanomaterials

This paper has illustrated though that there are differences between silica and CNT, particularly in their hazard profile – not all nanomaterials are the same. Silica is widely available in its nano form, and in some cases has been used for many years. Although it is not ‘safe’ it could be argued that it is unlikely to add significantly to the existing risks of demolition, particularly in relation to respirable silica (quartz) dust from concrete.

CNTs are at an early stage of commercialisation in the construction industry, and it is difficult to predict where, and how extensively, they will be used in the future. The academic literature is enthusiastic about their potential but scaling up production in a reliable and affordable way is proving challenging (NNI 2015). It is also unclear what types of CNTs might be used in construction and how robust and long-lasting the materials they are embedded in will turn out to be. This makes it impossible to judge the potential for harm to arise from their use, given that some forms are recognised as being hazardous. Ideally, developments of new products will focus on the use of CNT types which have been identified as less harmful (such as those which are short and tangled), but it is also possible that the drive for improved functionality will override this.

Building designers are unable to make informed decisions regarding risk without knowing what is being used and where. Currently, the most potentially problematic nanomaterials are not widely available in the marketplace but they are expected to appear in the near future; it is therefore essential that we learn more about them. Ideally, designers would have the relevant information regarding their hazard potential (as well as their potential to reduce risks) to aid decisions concerning product specification. In its absence, they can (hopefully) only err on the side of caution, taking precautionary measures during construction and keeping good records in the health and safety file passed on to the end-user. This will permit demolition engineers in the future to make sensible decisions when deconstructing buildings and facilities, in the light of the best available information available at that time.

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