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Nanomaterials in construction and demolition – how can we assess the risk if we don't know where they are?

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Abstract. This research, funded by the Institution of Occupational Safety and Health in the United Kingdom, has used a combination of literature review, web searching and unstructured interviews with a range of industry professionals to compile a list of products used in construction and the built environment which might contain nanomaterials. Samples of these products have been analysed using Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy to investigate whether nanomaterials are actually present and to what extent. Preliminary results of this testing are presented here. It is concluded that there is a discrepancy between the academic literature and the reality regarding the current application of nanomaterials in the construction industry and the built environment. There are also inaccuracies and deficiencies in the information provided by manufacturers which makes it difficult to accurately assess the location and application of nanomaterials within the industry. Further testing is planned to evaluate the risk of nanoparticle release from nano-enabled building products at their end of life by reproducing common demolition and recycling processes such as crushing, grinding, burning and melting. Results of this will form the basis of practical guidance for the construction, demolition and recycling industries to help them identify where particular protection or control measures may be appropriate as well as providing reassurance where no additional action is required.

1. Introduction

Construction is an important arena for the application of nanomaterials as the high volume of concrete, steel and glass used offers a substantial market for novel products. It is, unfortunately, also a sector where there is a high potential for causing harm, as the industry employs almost 15 million people across Europe who typically have high exposure to biological, chemical and ergonomic hazards [1]. Risks from the physical demands of the work are compounded by inadequate training in some parts of the sector and there are additional challenges associated with the highly varied and rapidly changing nature of the work environment. There is particular anxiety within the industry regarding the possible health risks of developments in nanotechnology. The construction and demolition industries deal on a daily basis with the legacy of asbestos, which was once lauded as a 'magical' material and used widely before its association with mesothelioma, lung cancer and asbestosis was recognised. There is concern that nanomaterials may represent a similar scenario, particularly in the light of findings that some carbon nanotubes may affect the body in similar ways to asbestos fibres due to their high aspect ratio and low solubility [2].



This paper describes a research project, funded by the Institution of Occupational Safety and Health (IOSH) in the UK, which addresses the application of nanomaterials in the built environment, in particular their impact in the demolition sector. Preliminary results are presented from the first year of this three year study, and the planned later stages of work are described.

The aims of the research include:

- to identify where nanomaterials are used in the built environment

A number of useful summary papers have explored this issue [3-8]. However, these are based largely on published academic literature and web searches, and are generally more effective at describing where nanomaterials have the potential to be used rather than where they are actually used in practice. There is no current requirement to label building materials which are nano-enabled, although recent legislation in France, Belgium and Denmark requires central reporting or registration of nano-enabled products.

- to assess the risks of nanoparticle release during refurbishment, demolition and recycling

Demolition and refurbishment tasks introduce particular challenges as dust generation is common and the exact provenance of building materials may not be known. High levels of recycling (95% or higher in the UK) [9] increase the exposure potential for workers stripping building materials out in an enclosed environment and also create additional exposure potential downstream.

- to generate guidance on how to manage this

The demolition industry in particular has had to adapt its practices to accommodate the presence of asbestos and other toxic materials in the built environment. This is only possible where there is a good understanding of where such materials might be found. User-friendly guidance on the level of risk posed by nano-enabled products is needed to support informed decisions regarding the demolition of buildings which may contain these materials. At the same time, there is a benefit for the construction industry as a whole in understanding the level of risk involved, to ensure that disproportionate anxieties do not prevent the industry from taking full advantage of the benefits of these new technologies.

2. Methods

The literature review has encompassed wider academic literature in addition to the summary papers mentioned above. It has also used web-based data, in particular the nano product inventory run by the Project on Emerging Nanotechnologies [10], The Nanodatabase in Denmark [11], and the specific inventory of nano-enabled construction products hosted by The Center for Construction Research and Training (CPWR) in the USA [12]. A further source of data is manufacturers' product sites, identifying construction materials either labelled 'nano' or having novel properties which might indicate nano-enablement.

Based on the literature, a summary table has been produced of construction products which might be nano-enabled. Samples of many of these have been collected either by requesting products directly from manufacturers or suppliers, buying them, or collecting offcuts from users. Preliminary testing of samples with Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDX) has been used to identify the presence of nanoparticles and the chemical composition of materials. Both the identification of possible nano-enabled products and the collection and analysis of samples are ongoing.

Interviews with builders and project managers, visits to construction sites and discussions with manufacturers are providing data regarding the current use of nano-enabled construction products. Interviews with demolition contractors and recycling specialists are being used to identify the common processes involved in recycling and demolition.

3. Preliminary findings

3.1. Overview of nanomaterials in construction

Interviews with those working in the construction industry have confirmed the relatively conservative nature of the sector. There is a very strong focus on cost effectiveness, with the suggestion that ‘market forces’ are the key consideration when selecting materials. Projects generally include the cheapest materials which will fulfil a particular requirement and, as one manager observed, “*they just want us to put bricks on top of bricks.*” The implication is that novel materials are not widely used, nor are they likely to be unless there are financial or regulatory reasons to do so.

Set against this is a quote from Bill Looney of AECOM who has suggested that “*By 2025, over 50 percent of building materials are expected to contain nanomaterials as more take advantage of these lighter, stronger, and more energy efficient materials*” [13]. If this prediction is accurate, we can expect to see a massive expansion of nano-use in the sector over the next 10 years. Although this seems unlikely given the generally slow evolution of materials and techniques, we may be at a tipping point where the use of new products will become more practical and/or cost effective, perhaps for the regulatory reasons mentioned above. For example, discussion with those working in the glazing sector has found that the use of soft-coated (i.e. nano-enabled) glass has increased rapidly in the UK in recent years as it is the most effective way of fulfilling the insulation requirements of the building regulations.

This research to date has highlighted the difficulties of accurately identifying nano-enabled products. Materials which contain nanoparticles are not required to be labelled as such. Material safety data sheets have been gathered for many products and rarely specify that the product contains nanoparticles. Email exchanges with manufacturers have met with a variety of responses – some are open regarding the presence of nanomaterials, some are reluctant to provide detailed information and some simply fail to respond.

In addition, many materials and products which are labelled as ‘nano’ do not actually contain nanoparticles, as this extract from a manufacturers’ product literature illustrates: “*[the] name derives from its nanotechnology, ... [the company] does not use Nano particles in any of its products.*”

In the current study, a supplier was contacted after microscopy of a purchased sample failed to identify the presence of nanomaterials; the response given was that “*Nanocoating is purely a name given to the treatment we offer for the [product], rather than a description of the material itself.*”

3.2. Common categories of nanomaterials in construction

The products identified by this research as being potentially nano-enabled are summarised in table 1. Samples of 35 of these products have been acquired. This section will proceed by providing further details regarding the four most common product types identified and illustrating these with initial results of microscopy. This table will be developed further during the course of the research, and sample collection will also continue.

Table 1. Number of construction products identified as being potentially nano-enabled.

Product type	Number of potential construction products
Surface coatings	58
Glass	23
Concrete	21
Insulation	10
Metal	8
Composites	1
Other (roofs, flooring, lighting)	16

3.2.1. Concrete. Microsilica (also known as silica fume) has been used as a concrete additive for over 20 years. Although the average particle size is around 150 nm, it is classed as a nanomaterial under the EU definition as more than 50% of the particles are less than 100 nm in size (although these account for only a small proportion of the material by mass). The small spherical particles contribute to concrete being self-compacting, dense (and therefore stronger at lower thicknesses), gaining rapid strength during curing, or having good flow for pumping to high levels. Most of the major concrete producers include microsilica-enabled concretes in their portfolio, although these are not always labelled as such. It was identified from interviews with industry professionals that microsilica-enabled concretes account for only a small proportion of the concrete market in the UK, largely because there are many other additives which provide similar properties and are cheaper or easier to use. Nanosilica (which is finer than microsilica) can also be added to concrete to produce a very high performance material but appears to be even less widely used.

The SEM results in figure 1 are from a sample of microsilica concrete and show nanoparticles to be present, but only a relatively small number. Discussions with professionals in the concrete industry have highlighted that much of the microsilica added at the mixing stage participates in the concrete reaction and is therefore no longer present as original microsilica particles once the material is cured. This would explain the small number of nanoparticles visible in figure 1.

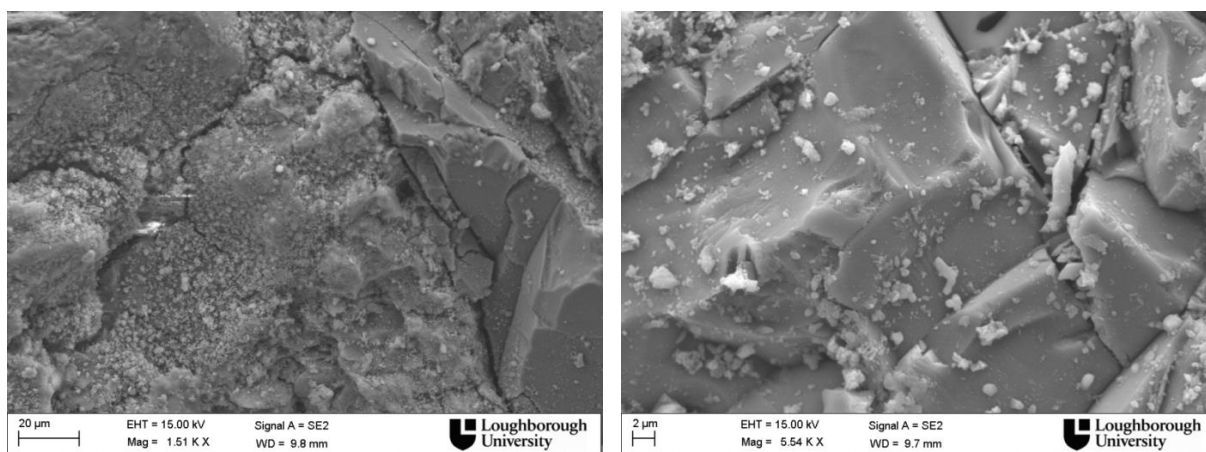


Figure 1. Scanning Electron Micrographs of microsilica-enabled concrete.

A second additive which can be used in concrete in its nano form is titanium dioxide, which is typically used to keep concrete clean and white or to absorb pollutants from the environment. It is used even less commonly than microsilica due to its high cost; where it is used, it is as a surface layer rather than being present throughout a concrete structure.

As figure 2 shows, only a very small number of nanoparticles are visible in the sample of nanotitanium concrete tested. Further work will be required to assess whether this unexpected result reflects the true state of nanotitanium concrete, or whether it demonstrates a poorly prepared sample. It is widely acknowledged that dispersion of nanoparticles is a major challenge in construction materials.

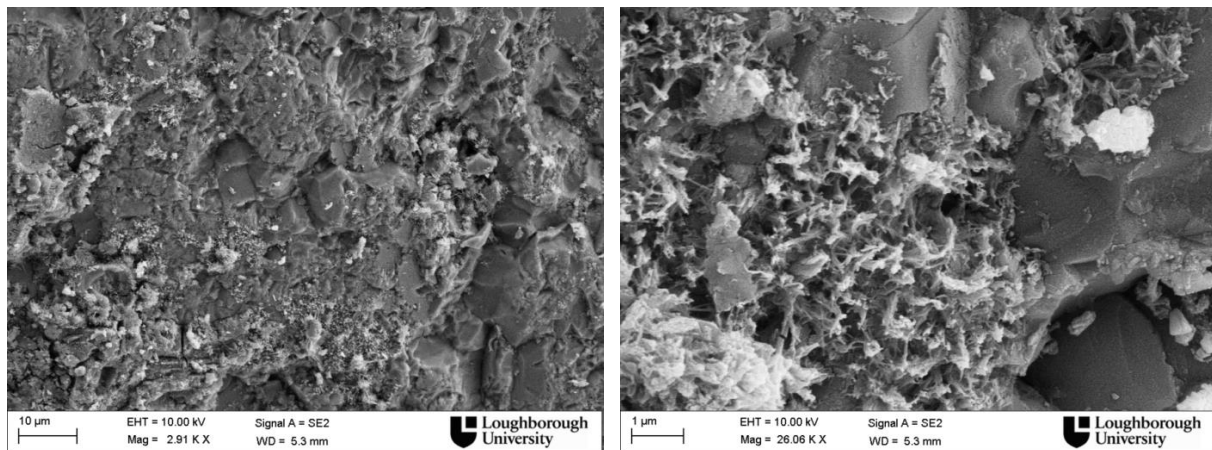


Figure 2. Scanning electron micrographs of nanotitanium-enabled concrete.

In conclusion, concrete is currently used to a limited extent in nano-enabled forms. Preliminary results suggest that the presence of nanoparticles in the cured concrete is also relatively low. Further testing will be required to confirm this and to assess how the material behaves under demolition-related processes. However, given that destruction of ordinary (non-nano) concrete generates large numbers of nano-sized particles [14], it is possible that the inclusion of nanomaterials such as microsilica (and maybe titanium) do not significantly increase any risk: and will remain less important than the existing risks from quartz silica, and can be managed through similar control measures.

3.3.2. Glass. Window glass appears to be the most widely used nano-enabled construction material. Almost all new buildings include windows which have nano coatings to improve thermal insulation, with these having displaced the more traditional ‘hard’ coatings in recent years. In addition, many conservatories and other glass roofed buildings have self-cleaning coatings, and the use of nanosilica intumescent layers has contributed to high grade fire safety glass for around 30 years. Other nano-enabled properties are available such as solar protection, anti-fogging, and electro chromic capability (which allows the user to vary light penetration through a window) but are less frequently used.

Glazing nanolayers are extremely thin (e.g. the Pilkington website gives a figure of 15 nm) [15]. As a consequence, the quantities of nanomaterials involved are low. This is demonstrated by the willingness of some glass manufacturers to reuse offcuts of coated glass within their float glass production, which is a highly sensitive process. Testing of nano-coated glass within this project is due to begin in the near future.

3.3.3. Insulation materials. The most commonly reported nano-enabled insulation materials are those based on silica aerogels. These materials are 96% air and have been described as “*the most effective thermal insulation on earth*” [16]. They are generally constructed as blankets which are wrapped around pipes or other structures or applied to plasterboard. They may also be used as insulation in translucent walls such as Kalwall. They are commonly described in manufacturers’ and academic literature as being ‘nanoporous’ [3] or nanostructured and as not generally containing nanoparticles. Two different brands of aerogel blanket have been tested to date, the results are shown in figures 3 and 4.

Insulation blanket A, as shown in figure 3, is constructed of fibres which then have micro and nano sized particles on their surface. The material is very dusty and releases particles when touched. Insulation blanket B is much less dusty in use. It is still constructed of particles and fibres, but the particles are not at the nanoscale (figure 4).

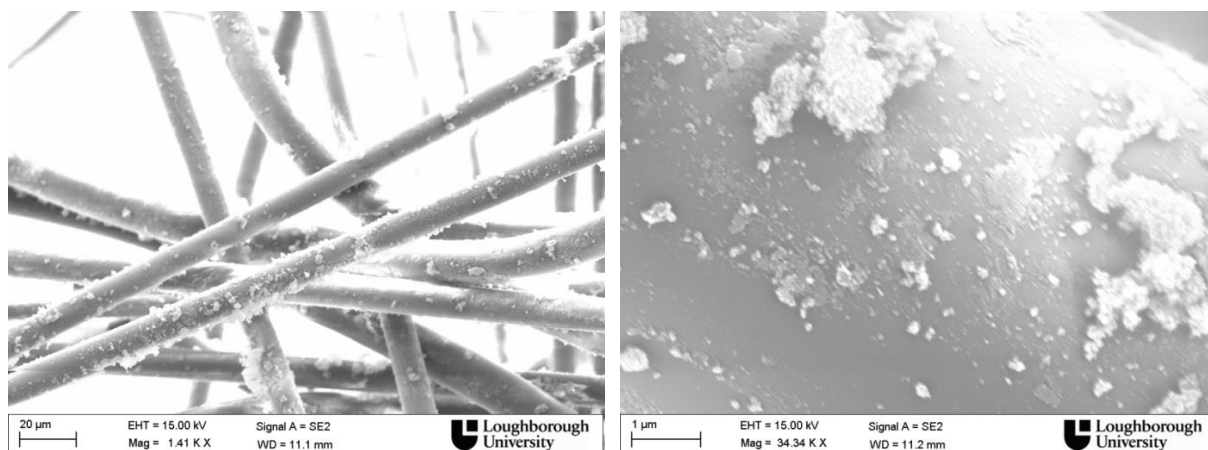


Figure 3. Scanning electron micrographs of Insulation blanket A.

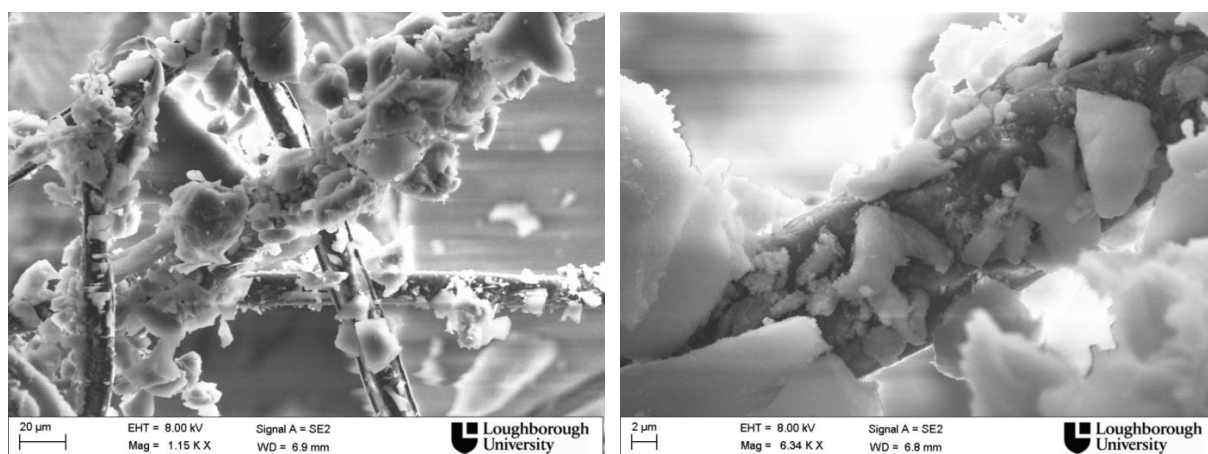


Figure 4. Scanning electron micrographs of Insulation blanket B.

In conclusion, not all insulation blankets are the same in their construction or their potential to release nanoparticles, despite being generally considered as a homogenous group within the literature. This topic hence warrants further consideration. Although amorphous nanosilica is commonly considered to be a relatively low risk material, it is important to assess the quantity and nature of particles released through use/removal of these products and compare these to the levels associated with possible health effects in the literature, for example those discussed by Napierska [17].

3.3.4. Surface coatings. Surface coatings are the most diverse nano-enabled products in the building industry. They are available for domestic use, are included in professionally applied coatings and paints, and can be incorporated on the surfaces of products such as ceiling tiles or toilets during manufacture. Many are silica based, providing water resistant or anti-graffiti properties. Others include titanium to enable easy cleaning and pollution absorption. A third category are those which include silver as an anti-microbial, although it can be difficult to distinguish between products which contain silver at the nanoscale and those which are based on different forms.

Figure 5 shows the structure of a surface render which is marketed as being easy to clean and thermally insulating, and as containing ‘nano-quartz’. As the micrographs show, the material contains both nano and micro sized particles. Further investigation is required to assess whether the particles are actually quartz, or whether they are amorphous silica, which seems more likely.

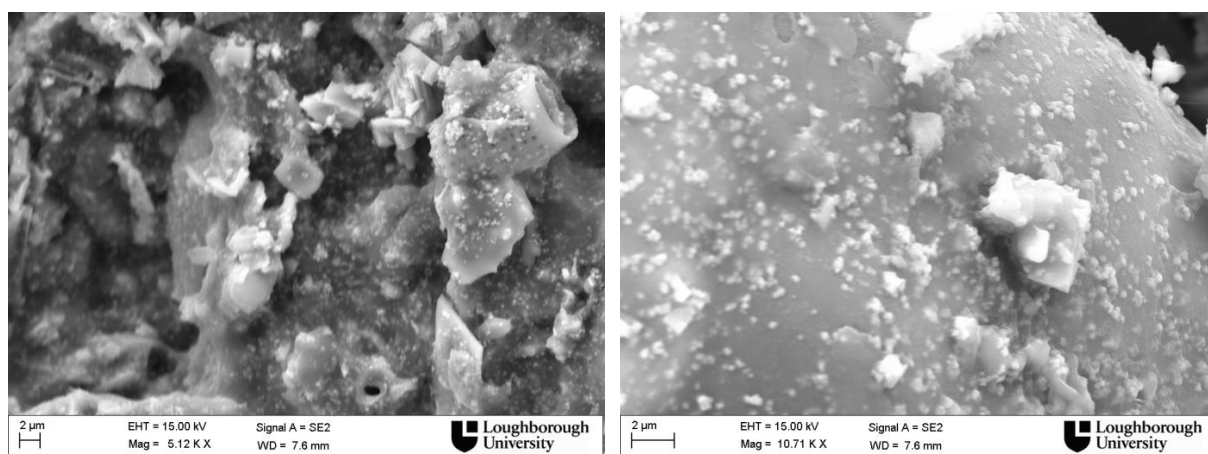


Figure 5. Scanning electron micrographs of a surface render.

The material shown in figure 6 is marketed for worksurfaces and other internal building uses which require scratch resistance and easy clean properties. It is described as a nanotechnology material but the micrographs suggest that it does not contain nanoparticles.

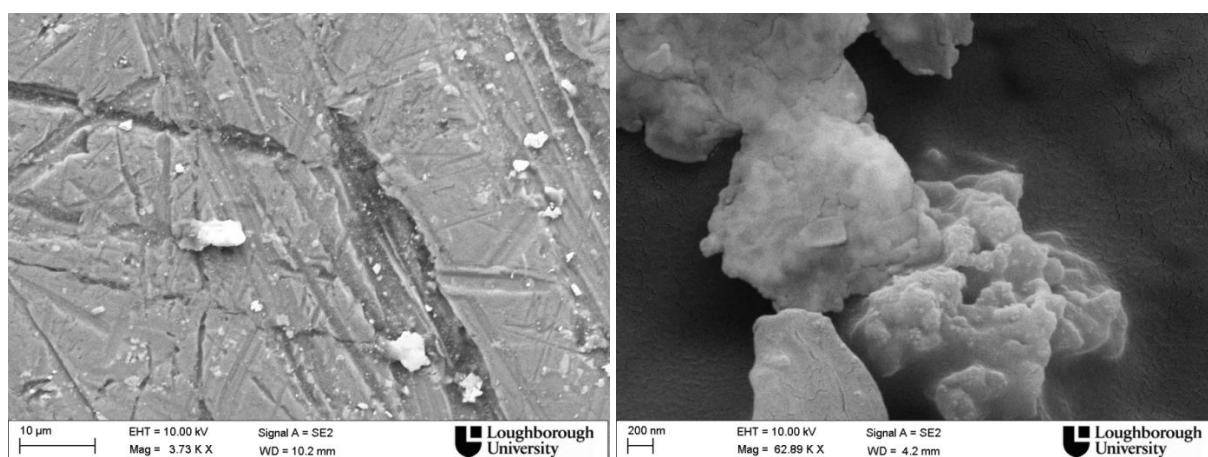


Figure 6. Scanning electron micrographs of a worksurface material.

In conclusion, there are a wide variety of nanomaterials used in surface coatings. It is possible that many products which are sold as being nano-enabled do not contain nanomaterials or do so in extremely small quantities. It is difficult at this stage to determine which, if any, might present potential health risks and drawing generic conclusions is likely to remain difficult due to the wide variations between products.

3.4. Carbon Nanotubes in construction

Carbon nanotubes (CNT) are widely discussed within the academic literature with reference to construction, identifying that they have the potential to enable concretes which are particularly strong or self-healing; or which are self-sensing and can transmit information regarding the state of deterioration of the material [3-8]. The papers which summarise the use of nano in construction generally refer to the benefits of adding 1% CNT to concrete, although it is not clear what the source of this figure is, as the wider literature explores a variety of concentrations as well as many different shapes and sizes of tube.

The literature also acknowledges that there are difficulties with the incorporation of CNT into commercial products due to high cost, low availability and difficulties dispersing tubes effectively. Interviews for the current research with those working in the industry have similarly indicated that the technology is some way from commercial use. However in recent months there have been developments in this field, with a recent report by Eden Energy stating that they are close to production and that “[a] preliminary trial in USA during the next 3 months of Eden’s CNT enriched concrete on a suitable roadway or similar area is scheduled” [18].

A second market for the use of carbon nanotubes in construction is in coatings or thin films. These take advantage of the material’s conductive capability and have the capacity to be used for heatable paints and to shield rooms from radio and microwaves. It is unclear how extensive this use is and in fact whether these materials are currently being sold to users or to interim manufacturers who will carry out further development and testing.

4. Ongoing research

Continued development of the list of potential nano-enabled products is ongoing, together with the accumulation and testing of further product samples to identify and characterise the nanomaterials. It is hoped to extend the range of products considered by gathering samples of CNT enabled products as well as composites and nanoclays. These materials have scope to be nano-enabled but do not yet appear widely in the marketplace.

The second stage of the research will involve a subset of the samples already tested. These will be subjected to a range of simulated demolition processes such as crushing and grinding (which are the most common end points for concrete and other aggregates and also currently for glass), as well as melting and burning and other processes involved in recycling.

5. Conclusions

This research has sought to identify where nanomaterials are located in practice in the construction industry. It has identified that there is a mismatch between the developments in the technology (as described in the literature) and availability in reality in the marketplace. It has also demonstrated that there is sometimes a disparity between the information provided by manufacturers regarding the nano-content of products and the reality; even where correct information is provided it is generally incomplete. There is no legal requirement to provide details to the user regarding the nanocontent of construction products.

It is difficult currently to draw firm conclusions regarding the risk potential from nanomaterials to those working in the demolition industry. It is anticipated that further testing will provide clarification in at least some areas and hence enable pragmatic guidance for the industry to be developed to indicate where particular protection or control measures may be appropriate and to provide reassurance where no additional action is required.

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