

Nanotechnology in construction and demolition

Guidance for industry



IOSH is committed to supporting health and safety research that has a practical application in the workplace. We're pleased, therefore, to have worked with Loughborough University to publish this guide on 'Nanotechnology in construction and demolition.'

Forming part of our Research and Development portfolio, this document joins IOSH's range of authoritative, free guidance, available at www.iosh.co.uk/researchreports.

Nanotechnology in construction and demolition

This document is aimed at designers, project managers, contractors, demolition engineers, suppliers and health and safety professionals in the construction and demolition industry.

The guide contains information and practical advice to help individuals and businesses manage nanomaterials as part of their work activities.

This guide can be downloaded at www.iosh.co.uk/nanotechnology

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1 Overview

This report is based on the study 'Nanotechnology in construction and demolition: what we know and what we don't'.¹ The research team at Loughborough University gathered information on the topic by reviewing:

- academic literature relating to nanotechnology and nanomaterials in construction
- literature on the health risks of nanomaterials
- manufacturers' websites and information for products which might contain nanomaterials: some products carried the term 'nano' in their advertising or name; others had properties such as being superhydrophobic or photocatalytic, which are often associated with nanomaterials.

To explore the extent of product usage, the team interviewed a range of people working in construction and demolition, and others working in the sale or development of nano-enabled construction products.

This report, based on the study, includes guidance for those working in the construction industry, including designers, contractors and health and safety professionals.

The key messages are as follows:

- Nanomaterials are found in construction products, primarily in surface coatings, concrete, window glass, insulation and steel. Not all contain nanoparticles.
- Some nanomaterials, such as certain types of carbon nanotube (CNT), are reported as being potentially harmful, although other nanomaterials and nanoparticles are considered much less problematic.
- Construction products containing CNTs do not currently seem to be in common usage in the UK.
- Even problematic nanomaterials such as long, straight CNTs will not be hazardous as long as they are embedded in a solid, stable structure. Risk only arises if workers are exposed to nanoparticles or nanofibres in the form of dusts or aerosols; this might occur during construction or demolition activities.
- Significantly more research is needed to provide robust evidence on the likelihood of free nanoparticles or nanofibres being released during construction and demolition activities.
- Designers and material specifiers in construction should ask questions of their suppliers so that they (and the industry) can understand better where nanomaterials (and particularly nanoparticles and nanofibres) might be in use.
- Where products containing nanoparticles and nanofibres (or other high aspect ratio nanomaterials) are specified or used, this should be recorded, eg in the CDM health and safety file or the building information model (BIM).
- Dust is a very significant hazard for those working in construction and demolition. The use of almost all currently available nano-enabled construction products is unlikely to add significantly to the risks already present. The priority is to manage existing risks robustly.

¹ Gibb A, Jones W, Goodier C, Bust P, Song M and Jin J. *Nanotechnology in construction and demolition: what we know, what we don't*. IOSH: Wigston, 2017.

2 Introduction

In recent years there have been many reports of new construction products with innovative properties, such as very high-strength concrete, self-cleaning windows and novel insulation materials. Many of these products are facilitated by nanotechnology: technological advances in electron microscopes have enabled the study and manipulation of matter at an atomic level. This new science has supported acceleration in the development of new products. It has been suggested that nanomaterials might account for up to half of our building materials by 2025.

However, concerns have been raised that some nanomaterials may be hazardous due to the presence of very small particles. There have also been similarities observed between some nanomaterials and asbestos fibres.

The research at Loughborough University was carried out to improve our understanding of how nanomaterials are being used in construction and what health risks might arise for those constructing or, in the future, refurbishing or demolishing buildings. The research also aimed to produce guidance to the industry on how to minimise any risks. Most guidance currently available focuses on health risks during the manufacture of nanomaterials, rather than during the installation and use of commercial products.

2.1 What are nanomaterials?

Nanomaterials are materials that have one or more dimensions in the range 1–100 nm (nanometres). They have particular properties or characteristics as a consequence of this, as many existing materials behave differently at the nanoscale. To give some context to the dimensions, consider that the thickness of a human hair is around 100 μm (ie 100,000 nm). Figure 1 shows a carbon fullerene that is around 1 nm across – the ratio between this and a small grapefruit is roughly similar to the ratio between the grapefruit and the world.

Some organisations, such as the European Commission (EC), define nanomaterials as materials that contain nanoparticles or nanofibres. This is because the presence of nanoparticles is the characteristic sometimes associated with health risk, and this is the primary focus of their definition. However, other organisations, such as the International Organization for Standardization (ISO), define nanomaterials more broadly, including those which have internal structures at the nanoscale without containing nanoparticles or fibres, eg they have nano-sized pores or holes; or those which are nanoscale films. The wider ISO definition is used in this report.

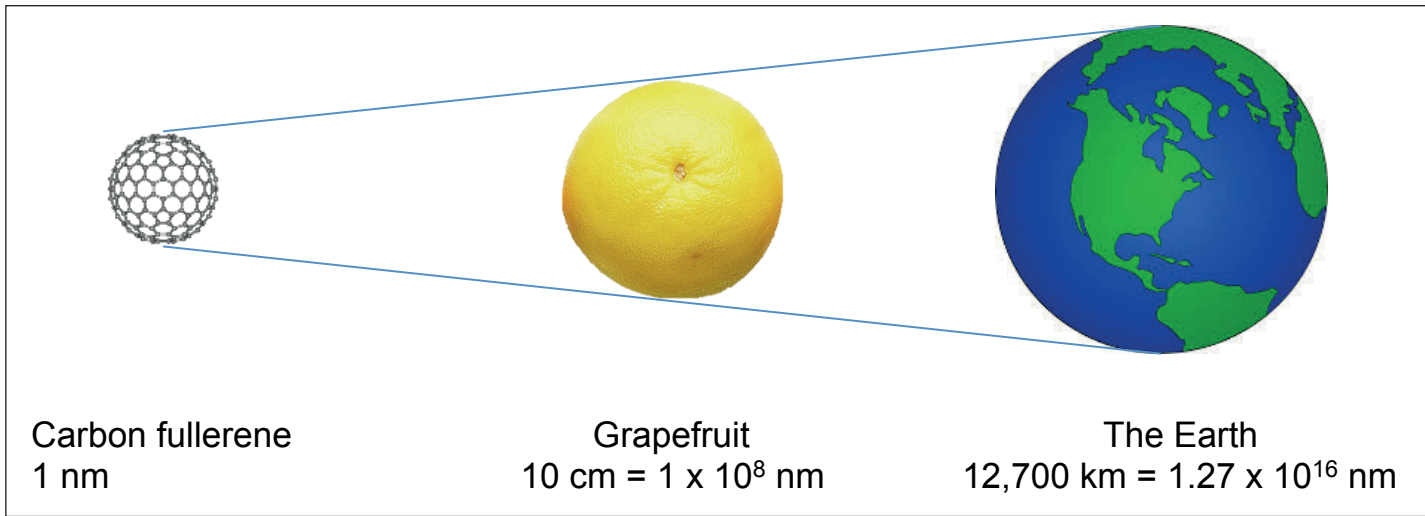


Figure 1: The ratio between a carbon fullerene, a grapefruit and the world

3 Are nanomaterials hazardous?

Having smaller particles increases the surface area of a substance, making it more reactive. In some cases, this will contribute to nanomaterial toxicity. However, many other factors influence toxicity, for example:

- what the substance is – the chemical composition and the particular type and structure
- how soluble the substance is
- how strongly the particles in the substance stick together (known as 'aggregation' and 'agglomeration')
- whether other substances or contaminants are present
- particle shape

Shape is particularly important. Fibres that are narrower than 1 µm and longer than 5–10 µm can become lodged in the lungs and be difficult for the body to clear via the usual protective mechanisms. Figure 2 illustrates one of these mechanisms and how its failure can contribute to ill health associated with asbestos fibres.

Three factors that influence the toxicity of fibres are diameter, length and bio-persistence:

- Fibres narrower than 1 µm can penetrate deep into the lungs – the fibre-like shape (high aspect ratio) enables them to travel a long way in, even if they are very long
- Long fibres are difficult for the body's usual protective mechanisms to remove
- If the fibres are particularly bio-persistent or durable in the body (ie if they don't break down or dissolve easily), this can increase the impact

Carbon nanotubes (CNTs) are an example of a nanomaterial with a fibre-shape: they are essentially a sheet of carbon, one atom thick, rolled into a tube. CNTs can be just a few nanometres in diameter, but many microns long. There is evidence that some CNTs are toxic and might cause cancer, particularly if the fibres are long, straight, stiff and insoluble (like asbestos fibres).

Other CNTs appear to present a much smaller risk: particularly, as shown in Figure 2, if they are short, or tangled rather than straight. New methods of making CNTs straighter, longer, and more separated have been developed in recent years, eg for use in electronics applications. This is a rapidly evolving area of research. Despite considerable research efforts, it is not clear which types of CNT are used in the very small number of construction products currently available.

High aspect ratio nanomaterials (HARNs) is the collective term for those materials (including CNTs) that are nanoscale in at least one dimension, and much larger in one or two of its three dimensions. Graphene is another example of a HARN – it is a nanoplate, being nanoscale in one dimension, but much larger in the other two. Like fibres, it has the potential to penetrate deep into the lungs but may then be too large for easy removal by the body's normal protective mechanisms.

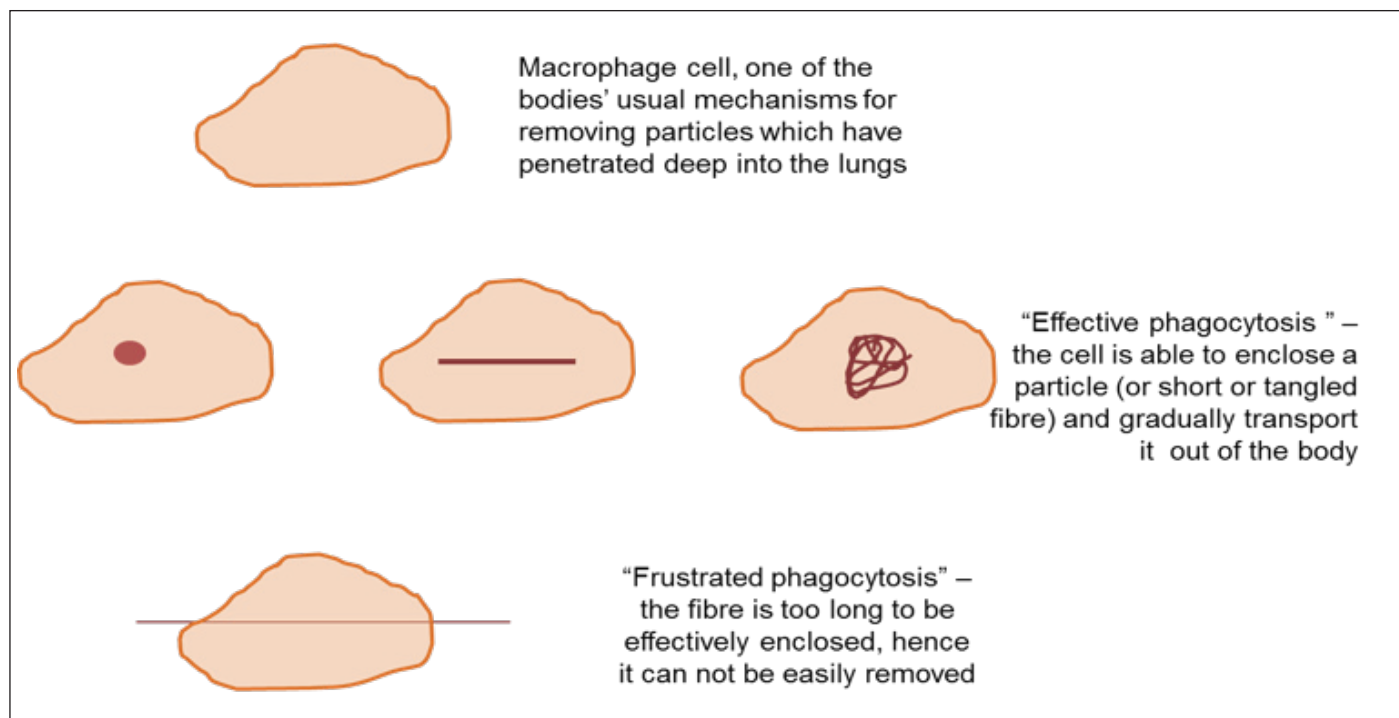


Figure 2: How fibre characteristics can influence removal from the body

Information currently available about the health risks from nanomaterials is based on laboratory research rather than on cases of ill health in workers. The results of studies are often inconsistent or inconclusive due to variations in the methods and exact test materials used. For example, amorphous silica nanoparticles² are considered to be relatively low risk, with any ill effects being largely reversible. However, there is insufficient evidence to declare nanosilica as 'safe', particularly as there are so many different forms of it in use. The situation is similar for other nanomaterials, with wide variations in the materials used and relatively little conclusive evidence regarding toxicity.

Even problematic nanomaterials – such as long, straight CNTs – will not be hazardous as long as they are embedded in a solid, stable structure. The toxicity only becomes a problem if workers are exposed to nanomaterials in the form of dusts or aerosols, eg during construction or demolition activities. Only a small number of studies have assessed the impact of these processes. Some of these studies have found that nanoparticles remain attached to fragments of the underlying matrix when products such as concrete or coatings are broken down. In this case, the particles would be too large to penetrate deep into the lungs. However, the research is limited and a few studies have found evidence of free nanoparticles being released.

Additionally, material ageing and exposure to weather over time can increase the risk of free nanoparticles being released, although again the number of studies that have assessed this is small. Significantly more research is needed to provide robust evidence on the likelihood of free nanoparticles being released during construction and demolition activities.

² Nanosilica is nearly always amorphous. This form of silica is not the same as crystalline silica found in cement-based products, which is recognised as a major hazard in the construction industry, particularly as a dust.

4 Where are nanomaterials used in buildings?

It's difficult to identify with certainty the construction products that are likely to contain nanomaterials as they are rarely precisely labelled. A product that is described or marketed as 'nano' may contain nanoparticles or nanofibres; may be nanostructured (ie contain nanoscale holes); may be based on nanoscale film; may have been developed using nanotechnology; or may carry the term solely to make the product seem new and different. Other products may contain nanomaterials, but the manufacturer might choose not to declare this.

One of the things that make it difficult to identify where nanomaterials are used is the way that health and safety legislation applies in different countries. For example, under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) and CLP (Classification and Labelling of Products), manufacturers and suppliers are required to declare if materials are known to be hazardous; and to produce safety data sheets so that users can carry out risk assessments as required under the UK's COSHH (Control of Substances Hazardous to Health) Regulations.

However, they are not required to provide information (to consumers or to regulators) about the specific use of nanomaterials in construction products: if they are present, what form they take, or what quantities or proportions are contained.

4.1 Window glass

Nanomaterials can be added to glass during production in the form of a very thin film, which provides special properties for windows. Glass with improved insulation properties is quite widely used, especially in the construction of commercial buildings, although more traditional versions based on non-nanomaterials are also available. Nanofilms can also be used to reduce the amount of solar gain within a building. 'Smart' windows allow solar gain to be varied to accommodate changes in the weather, although these products are currently very rarely installed.

Self-cleaning glass has a film of nanoscale titanium dioxide that acts through photocatalysis (the breakdown of dirt through interaction with sunlight to form debris that is washed away by rain water). It is quite widely used, for example, in conservatory roofs or in windows that are not easily inaccessible.

High-specification fire safety window glass has been available for many years for use in high-risk situations (eg to protect fire escape routes). It has a layer of nanosilica between the glass panes. In a fire, the pane near the fire fractures but stays in place. Then, the nanosilica swells and forms an opaque and resilient barrier, absorbing the energy of the fire.



Figure 3: The roof of St Pancras station in London, reportedly constructed using self-cleaning glass

4.2 Insulation

Nano-enabled insulation materials are generally based on silica aerogels. These are formed by replacing the liquid in an amorphous silica gel with air, leaving a material that is around 97 per cent air in a silica framework.

Aerogels are commonly described as being 'nanoporous' or 'nanostructured', and as not containing nanoparticles. The aerogels can be added to a fibre matrix to form insulating blankets, which can be wrapped around pipes or applied to plasterboard (see Figure 4). Aerogels can also be used as translucent granules in walls or ceiling materials to allow daylight entry; or enclosed inside impermeable laminates to form vacuum-insulated panels (VIPs). These materials are highly effective insulators, but are expensive and currently not widely used outside of specialist projects.

4.3 Concrete

Nanosilicas with various particle sizes can be added to concrete (eg silica fume, fumed silica) to produce materials that are stronger, achieve strength earlier, or are self-compacting. These have been available for many years, although usage in most countries is still relatively low.

Titanium dioxide particles provide concrete with self-cleaning properties due to photocatalysis and can also reduce atmospheric pollution. Usage appears to be very limited at present.

CNTs can be added to concrete to improve strength and potentially allow electrical conductivity. CNTs are expensive and difficult to work with. Only one CNT-enhanced concrete, launched in 2016 in the USA and subsequently in Eastern Europe following large-scale field trials, appears to be commercially available.

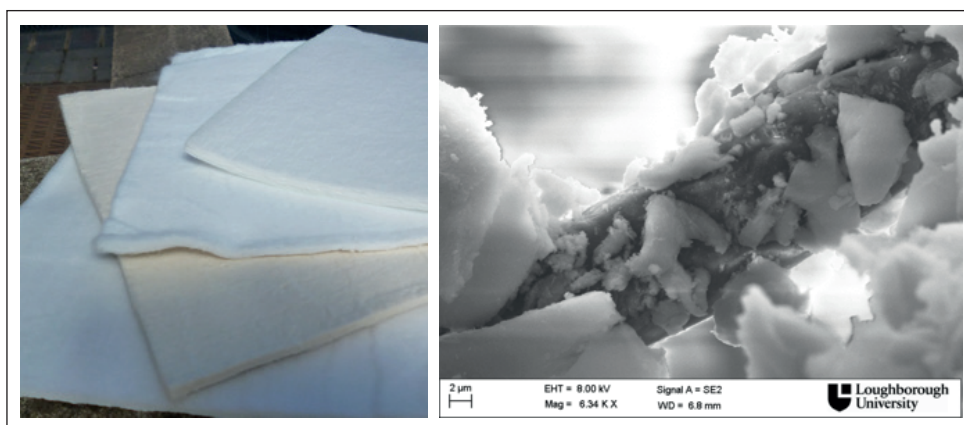


Figure 4: A selection of aerogel blankets, and the internal structure of one, showing aerogel particles around a polymer fibre³

³ The particles contain nanoscale holes or pores, but are not nanoparticles: the scale bar is 2 µm (2,000 nm) and the particles would need to be 1/20th the size of this or smaller to be nanoparticles.

4.4 Coatings

Coatings are the most numerous and readily available nano-enabled products in construction, available for both professional and DIY use, as well as being applied to products during manufacture. Many coatings contain silica (either as particles or in polymers) and are sold as having waterproofing or easy-clean/dirt-repellent properties.

Coatings may also contain titanium dioxide nanoparticles, which provide self-cleaning properties through photocatalysis; or antimicrobial silver nanoparticles (although not all silver antimicrobials are nanoscale).

CNTs can be added to coatings to provide strength, corrosion resistance and conductivity, but only a very small number of such products are commercially available. Graphene is reportedly used in this way. Figure 5 shows a product that is advertised as containing graphene, although microscopy shows nanoscale graphite is the probable content of the nanoplates. These are much thicker than graphene nanoplates (which would be only a few nanometres in thickness). Carbon black (which is made up of spherical particles, not fibres) is a much more commonly used (and familiar) nanomaterial. It is used, for example, for shielding against radio waves.

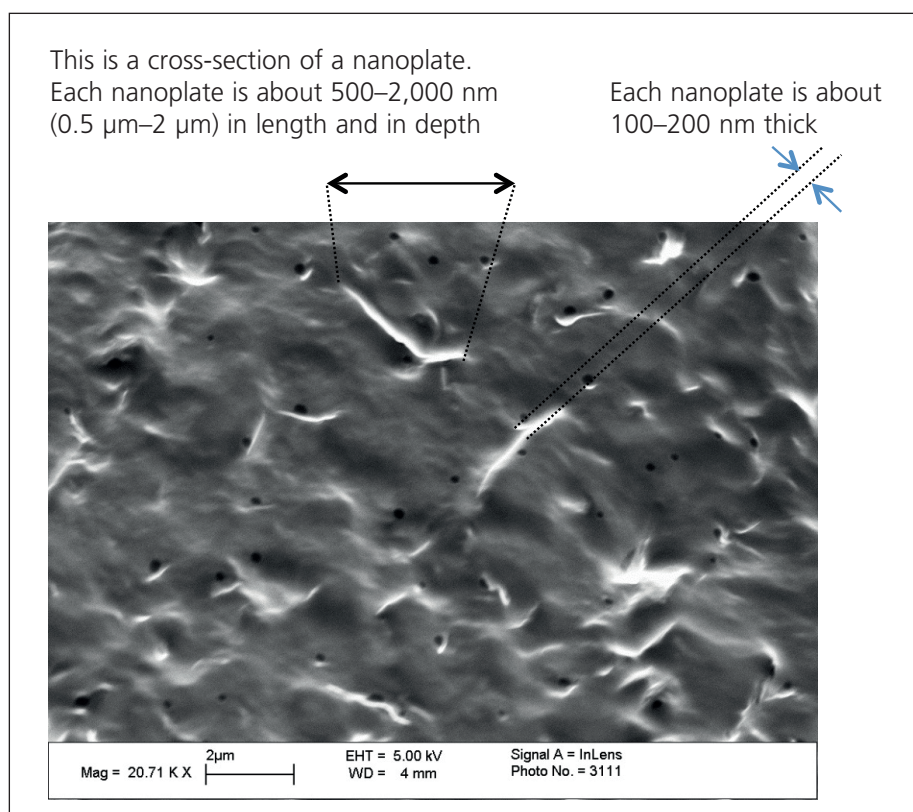


Figure 5: Electron microscopy picture showing a nanoscale graphite coating⁴

⁴ Multiple layers of graphene, stacked together to form plates that are around 100–200 nm in their smallest dimension.

5 What should we do about nanomaterials?

There is no straightforward answer to the question: 'Are the nanomaterials that are used in construction hazardous?' Although some may be problematic, others are believed to be considerably less so. There is wide variation in toxicity between different substances and even between different forms of the same substance; and it can be difficult to identify the exact details of the nanomaterials used in construction products.

Most of the nano-enabled products used in construction are based either on nanoscale films (which do not actually contain nanoparticles) or on substances considered to be at the less-hazardous end of the spectrum (such as amorphous nanosilica particles). However, those which are of more concern (such as carbon nanotubes) are starting to be used more widely. This is illustrated in Figure 6. The absence of a scale in the figure reflects the lack of certainty about both usage and toxicity of nanomaterials, although the general principles are understood. The Health and Safety Executive and others recommend a 'precautionary approach' – if there is reason to believe that harmful effects might occur, even if this is unlikely, precautions should be taken. However, it is also recommended that the focus should be on the highest risks and that action taken should be proportionate.

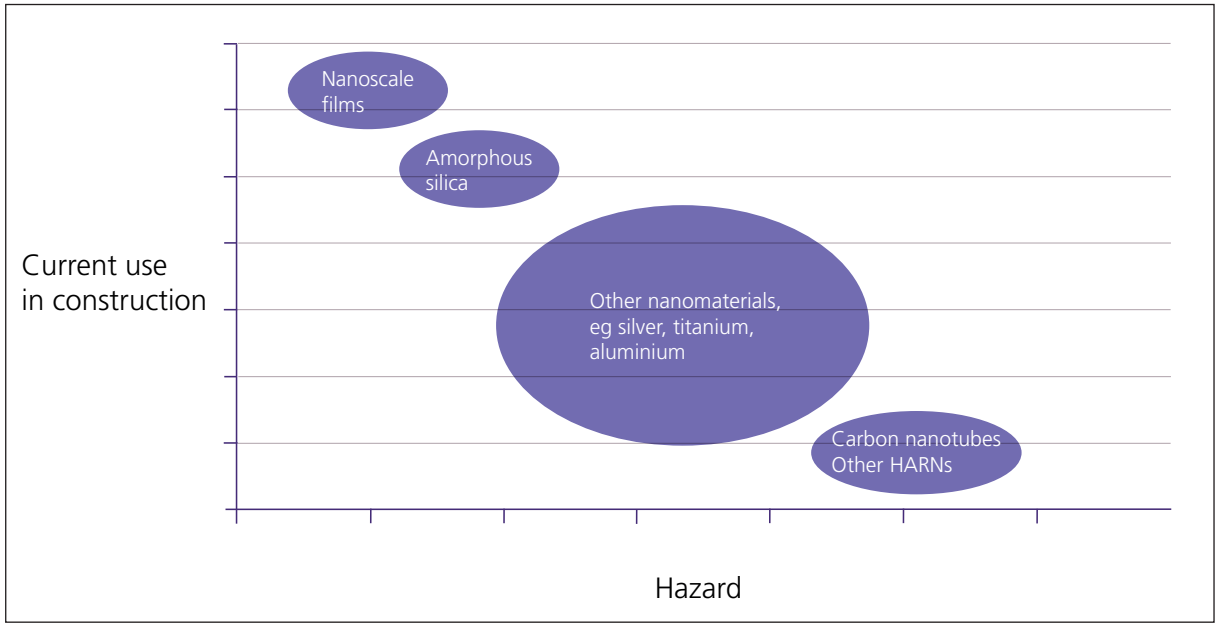


Figure 6: Current nanomaterial use in construction

Note: The nanomaterials currently used in construction are generally those which are considered to be less harmful. Those that may be more toxic are currently used only in specialist situations.

5.1 Guidance for those working in construction and demolition

Manage existing risk

Construction and demolition are hazardous industries in their own right, and the use of most nano-enabled products is not likely to increase the hazard level substantially. For example, the presence of amorphous nanosilica and silica fume particles in concrete may not add significantly to the major risk already present from respirable crystalline silica dust. Similarly, organic solvents used in coatings are likely to be a more significant risk at application than the presence of nanosilica particles. The priority, therefore, must be to ensure that good practice is integrated into all construction work, managing risks from both existing and new materials.

Ask questions

Where new materials are being used with novel properties, designers, construction professionals and those who supply materials should be more inquisitive. They should be asking questions of their suppliers and of the manufacturers: not just 'what substance is in this product?' but 'what size and shape are the particles in this substance?' In particular, users should ask suppliers of novel products whether they contain nanofibres or nanoplates, particularly those which are greater than 5 µm in length, as fibres above this length can be more difficult for the body to clear. It is recommended that they seek specialist guidance if such fibres or other particles are present.

Balance benefit and risk at the design stage

As discussed earlier, nanomaterials vary in their toxicity. Furthermore, they may be specified in designs because they have the potential to reduce or eliminate hazard. For example, self-cleaning glass reduces the need to clean the window and hence work at height; paints and coatings with a longer life reduce the need for re-application. It's important for designers to explore benefit and risk by asking questions at the earliest stage. Where risk outweighs benefit, or where risk is high (regardless of benefit), less hazardous products should be specified.

Record where nanomaterials are

If designers and specifiers have stipulated that they require products that contain nanoparticles, particularly if these are fibres or other HARNs, they should record the nature and location of the nanomaterials. This information could be recorded in the CDM health and safety file or the BIM. This will enable future generations to respond suitably once more detailed knowledge regarding toxicity is available.

Use risk control measures for nanomaterial-based products

Wherever possible, site risks should be controlled through the use of collective measures, such as extraction and dust suppression. Personal protective equipment (PPE) may be required where control is not possible by any other means, or to provide secondary protection. If liquid nanomaterials are being used (eg spraying coatings onto a surface), then a full-face mask with a P3 filter should be used. Otherwise, an FFP3 filtering half-mask will provide a suitable level of protection, provided it is properly face-fitted.

This is the same standard of mask that is recommended for protection against quartz silica and other hazardous materials in construction. Although the pores in such a mask are larger than nanoscale particles, the particles will be attracted to the mask fibres by electrostatic and other forces, and thus prevented from passing through. Nitrile-coated gloves and non-woven clothing (such as fleece for dry products, and Tyvek for liquids and aerosols) are also recommended.

A higher level of protection should be considered if there is a risk of exposure to CNTs or other HARNs. Here, the HSE advises that an FFP3 mask is sufficient if used in addition to other control measures, but that a mask with an assigned protection factor (APF) of 40⁵ should be used if uncontrolled airborne CNTs or similar substances are present. Currently, CNT-enhanced building products are rare, but they may become more widespread in the next few years.

A summary of the recommended construction or demolition phase actions in relation to nano-enabled construction products is presented in Figure 7.

⁵ A mask with an APF of 40 typically reduces exposures to around 1/40th of the level in the atmosphere. More commonly used FFP3 masks have an APF of 20, reducing exposure to 1/20th, ie no more than 5 per cent of the contaminant will get through the mask provided it is face-fitted and used appropriately.

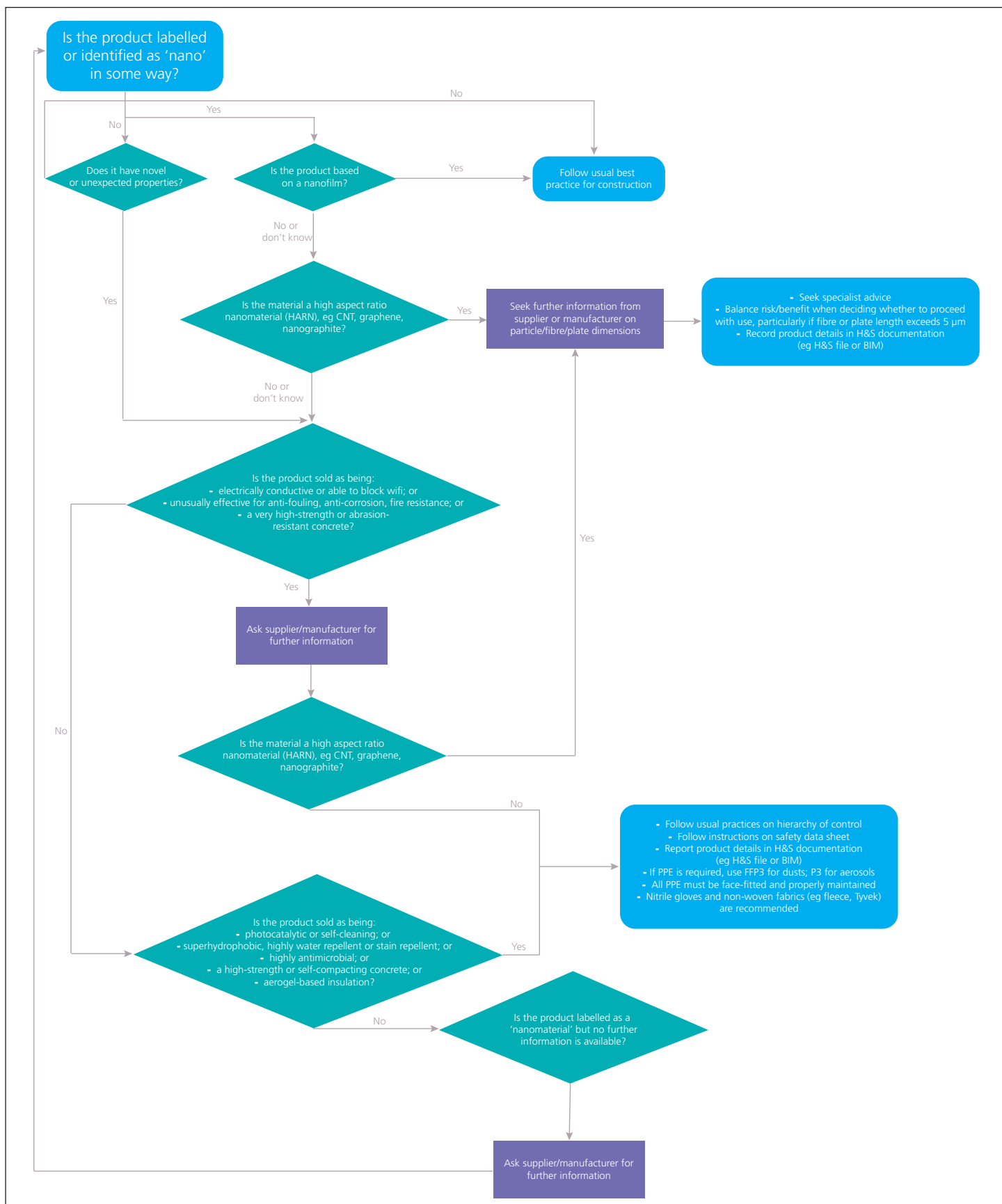


Figure 7: Summary of construction or demolition risk management for work involving nano-enabled construction products

5.2 Guidance for manufacturers of nanomaterials or products which contain them

Consider risk at an early stage, designing it out where possible

Manufacturers must consider the potential health risk from new nanomaterials at an early stage of development and recognise it as a key factor alongside functionality and cost. This information can then be used to support decisions to discontinue the development of problematic substances or to find ways to redesign them. Nanomaterials can be made 'safe by design': toxicity can be reduced, for example, by making CNTs shorter or graphene particles smaller. Other modifications can also reduce the potential for harm, such as adding particular chemical elements or molecules, attaching particles to larger structures, or improving the stability of nanoparticles within matrices.

Those developing construction products that contain nanomaterials should review the appropriate toxicity data and balance the risks and benefits of using nanomaterials.

Share information widely and effectively

Information about the nanomaterials used in products should be shared with suppliers and users downstream. For example, manufacturers could comply with ISO guidance on how to complete safety data sheets in respect of nano-enabled substances.⁶ If companies voluntarily followed such guidance and operated 'good practice', this would provide useful information for industry to support their risk assessments and would also facilitate research on the real-world impact of the materials being used.

5.3 Research needs

There are very few research studies that assess workers' exposures to nanoparticles and nanofibres during construction and demolition. Additional work is needed to assess the exposure impact of construction products in real-work situations and scenarios. Such research would be made easier if products were better labelled and described by manufacturers.

This research needs to develop alongside research strands that assess nanomaterial toxicity – these often focus on specific nanomaterials in their 'pristine' condition, but need to be extended to assess the toxicity of dust arising from the use of nano-enabled construction products.

⁶ *Nanomaterials – preparation of material safety data sheet (MSDS)*. ISO/TR 13329:2012.

6 More information

More information is available in the main research report associated with this publication – see www.iosh.co.uk/nanotechnology

Other useful resources include:

- *Using nanomaterials at work*, HSG 272 (HSE, 2013)
This HSE publication is not specific to construction but gives detailed guidance for those working with CNTs and other HARNs.
- <http://nano.elcosh.org>
The eLCOSH Nano database lists around 500 construction products that are believed to contain nanomaterials in some form. It is US-based, but many of the products are also available in the UK and across Europe.
- <http://scaffold.eu-vri.eu>
The European Scaffold project has published a number of reports based on research in nanoparticle release in construction. Further guidance, including an online risk management tool for construction nanomaterials, is expected in late 2017.

7 Definitions and glossary

BIM: Building Information Modelling

The process of developing information-rich object-oriented models. The term is sometimes used to denote the models themselves.

CDM: The Construction (Design and Management) Regulations (2015)

These UK Regulations set out the processes and duties to ensure construction projects are carried out in a way that secures health and safety.

CLP: Classification, Labelling and Packaging of substances and mixtures Regulation

This EU Regulation came into force in January 2009. It adopts the United Nations' Globally Harmonised System on the classification and labelling of chemicals across all European Union countries, including the UK.

COSHH: Control of Substances Hazardous to Health Regulations (2002)

COSHH Regulations require employers within the UK to control substances that are hazardous to health.

CNT: Carbon nanotube

Carbon nanotubes are hollow structures with a diameter between 1 and 100 nm, and a length of several microns or longer. They may have a single wall or may consist of several tubes inside each, multi-walled carbon nanotube.

Nano-enabled

Exhibiting function or performance only possible with nanotechnology.

Nanofibre

Nano-object with two similar external dimensions in the nanoscale and the third dimension significantly larger.

Nanomaterial

Material with any external dimension in the nanoscale or having internal structure or surface structure in the nanoscale.

Nanomaterial, EU definition

A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or agglomerate and where, for 50 per cent or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm to 100 nm.

Nano-object

Discrete piece of material with one, two or three external dimensions in the nanoscale.

Nanoparticle

Nano-object with all three external dimensions in the nanoscale.

Nanoplate

Nano-object with one external dimension in the nanoscale and the two other external dimensions significantly larger. The smallest external dimension is the thickness of the nanoplate; the two significantly larger dimensions are considered to differ from the nanoscale dimension by more than three times; the larger external dimensions are not necessarily in the nanoscale.

Nanoporous material

Solid material with nanopores (the solid may be either amorphous, crystalline, or a mixture of both); the definitions of solid nanofoam (where most of the volume is occupied by pores) and nanoporous material (also materials with a small fraction of pores covered) are overlapping.

Nanoscale

Size range of approximately 1 nm to 100 nm.

Nanostructure

Composition of inter-related constituent parts in which one or more of those parts is a nanoscale region.

Nanostructured material

Material having an internal nanostructure or a surface nanostructure.

Nanotechnology

Application of scientific knowledge to manipulate and control matter predominantly in the nanoscale to make use of size- and structure-dependent properties and phenomena distinct from those associated with individual atoms or molecules, or extrapolation from larger sizes of the same material.

REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals (2006)

This European Union Regulation came into force initially in June 2007, with the final stage of implementation due in 2018.

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IOSH is the Chartered body for health and safety professionals. With more than 46,000 members in over 120 countries, we're the world's largest professional health and safety organisation.

We set standards, and support, develop and connect our members with resources, guidance, events and training. We're the voice of the profession, and campaign on issues that affect millions of working people.

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