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Innovation in **materials**

Summary of a meeting held on Monday 11 November 2013 at the Royal Academy of Engineering in association with The Institute of Materials, Minerals and Mining and the Materials Knowledge Transfer Network.

The Institute of Materials,
Minerals and Mining

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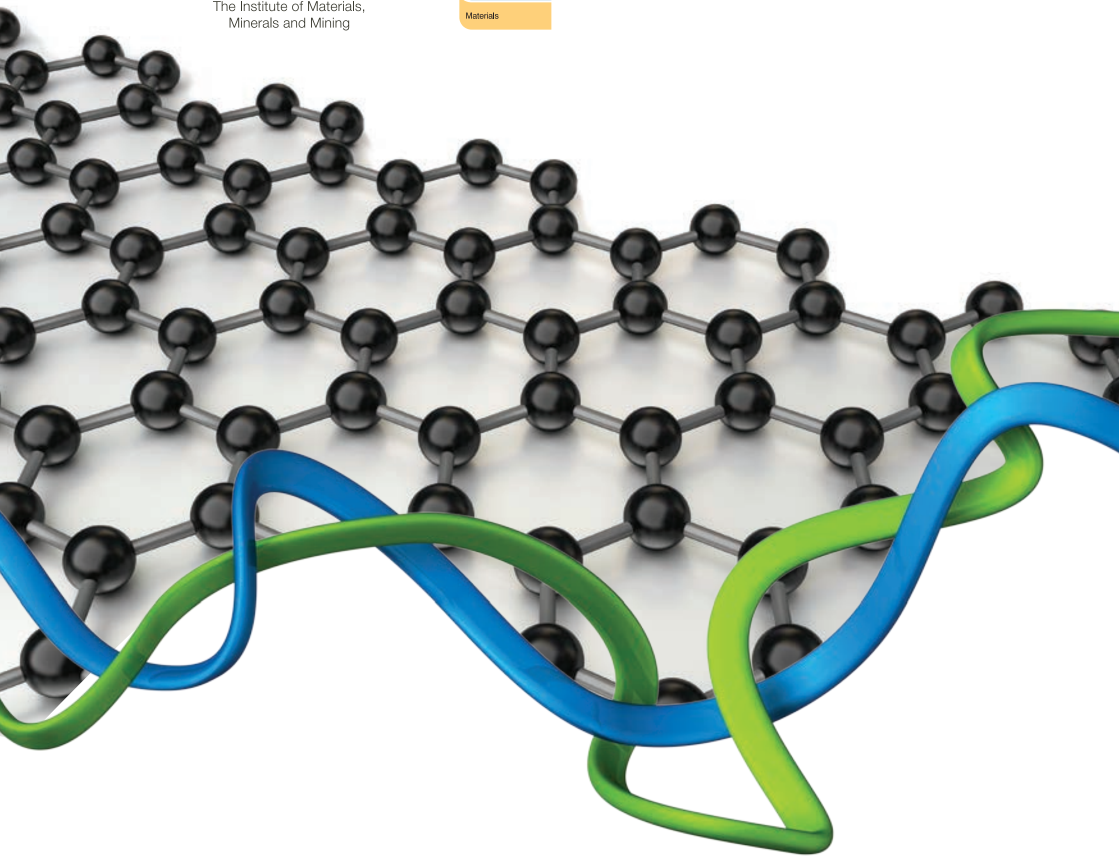

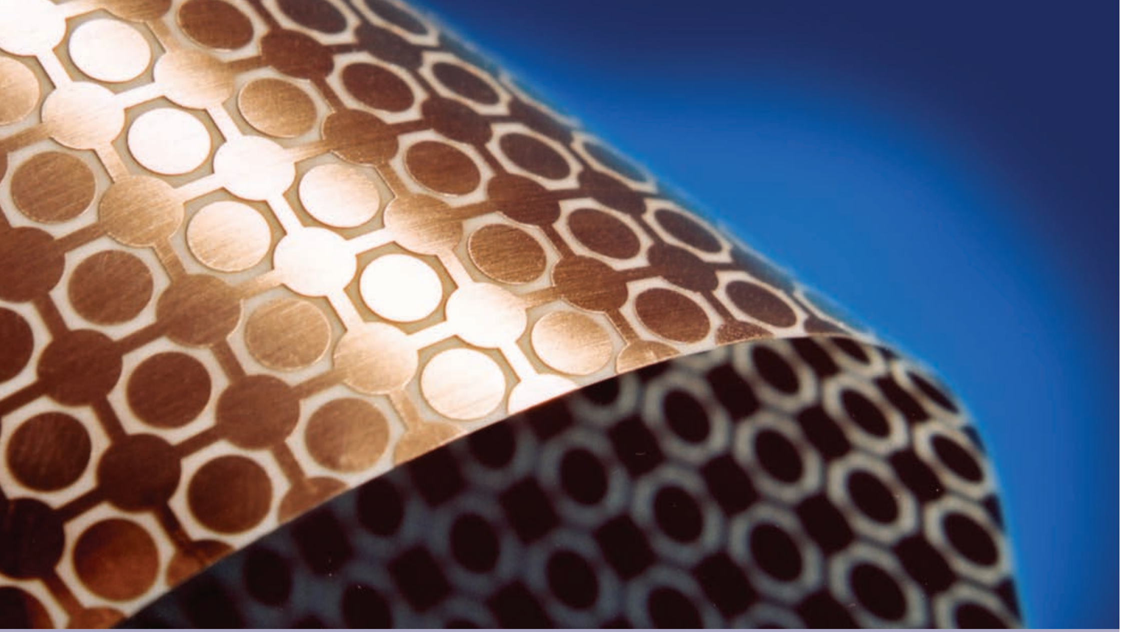

Stealth materials © 2014 BAE Systems

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www.raeng.org.uk/materials

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1. Foreword

The Royal Academy of Engineering has run a series of meetings to highlight the opportunities and challenges of innovation in engineering sectors that have potential for growth and global reach. On 11 November 2013, *Innovation in materials* brought together leading engineers, academics and business people from many branches of engineering – and beyond – to discuss issues and trends.

Materials have undergone a revolution in the past century, but in many respects the revolution is only just beginning. Not much more than 100 years ago, the range of materials used by engineers in products and systems was very limited: natural materials, many of which had been used since prehistory; a limited number of metals in fairly uncomplicated metallurgical forms; and a few plastics and ceramics. The developments of the 20th century expanded greatly the number of materials and our knowledge of their properties, and brought materials science much more close to manufacturing as we sought to design the properties we wanted from engineered products.

Now, in the 21st century, the ability to design new materials and to modify existing ones is still only in its infancy, and the potential is limitless and exciting. The possibility of influencing material composition and properties at the atomic scale creates opportunities that we are only just starting to explore; the convergence of biology, physics and chemistry is breaking down barriers. Innovation in materials is transforming engineering and the world that we live in.

The meeting heard presentations from academics, industrialists, innovators, materials scientists and users. This report is not a verbatim record of the conference; rather, it seeks to highlight some of the issues raised and to contribute to further discussion.

> Worldwide, materials are seen as a priority for innovation but also as a source of competition and advantage

2. The UK and global materials perspective

The UK has a long tradition of materials innovation, from the Bessemer steel process in the mid-19th century through to the Nobel Prize-winning developments in graphene at the University of Manchester. The minerals and mining industries were fundamental to the first Industrial Revolution in the UK. The UK industry that is involved today in products, processes, fabrication and recycling of materials is worth around £197 billion a year.

Materials research and development is at the heart of much of current public and privately financed work at universities and in companies, and the Technology Strategy Board has identified energy and sustainability as the main drivers for current materials development. 'Advanced materials' is one of four 'enabling technologies' – the others are biosciences; electronics, sensors and photonics; and information and communication technologies – that are seen as having a key role in helping UK businesses to develop high-value products and services across all economic sectors and to generate significant growth for the economy.

The Royal Academy of Engineering supports, along with partners in business and industry, several research programmes involved in materials development. Materials have also formed part of submissions for both the Queen Elizabeth Prize and the Annual MacRobert Award for engineering innovation.

Worldwide, materials are seen as a priority for innovation but also as a source of competition and advantage – and some concern. Research by Yale University into 62 metallic or metalloid elements that have current uses, often in commonplace but technically advanced devices such as smartphones that did not exist a generation ago, found that none of the 62 could be readily substituted across the range of their applications by other materials.

So-called 'strategic materials' include those that are currently believed to be in short or constrained supply; these are the subject of political and diplomatic manoeuvring and can create international tensions as countries seek to safeguard supplies or to use their availability as a political or economic lever. But materials are seen also as central to a less strident, more benign economic development – the potential for a 'circular' economy in which products and systems are designed from the outset with the intention that the materials should be reconfigured for reuse at the end of their lifecycle.

> Potential for a 'circular' economy in which products and systems are designed from the outset with the intention that the materials should be reconfigured for reuse at the end of their lifecycle

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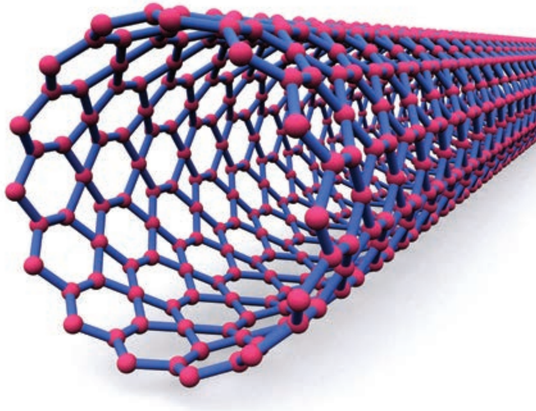

3. Materials in the engineering response to the biggest issues

Innovation in materials in the 20th century was about "working out how materials work and about the different structures inside them", said Professor Mark Miodownik, Professor of Materials and Society at University College London and Director of the Institute of Making, who gave the keynote address at the meeting.

For the 21st century, the focus on innovation will be about applying this knowledge to enable significant progress on solving problems of energy provision and the environment, he said. There was a contrast, however, between the scale of the issues that needed to be addressed and the level at which much of the research and innovation work was taking place: the focus of research in areas such as materials modelling was at the nanoscale. "But", he pointed out, "the big problems won't be solved down there."

A great challenge for material scientists, Professor Miodownik said, was "to link the scales together": to replicate in large-scale devices and systems the materials phenomena and properties that were now being seen and developed at the nanoscale. "For instance, with carbon nanotubes, if we could make these bigger, we could make huge strides. The big gains will come with mass production into larger structures." Nature and biology already did this with a unified materials structure that encompassed the very small and the very large in an integrated hierarchal structure, he said: "We have to learn how to do this in our human-built environment."

Professor Miodownik identified two further challenges for materials innovation in the 21st century: recycling, and the interface with biology. Processing and recycling are questions for the whole of mankind. "We are really not a credible set of people if we create sophisticated stuff and then when we've finished with it we put it in holes in the ground," he said. "It makes it seem as if we're not intelligent enough to have done the full lifecycle." Bigger examples were needed of 'closed loops', where materials were fully recycled into new materials at the end of a product's life and nothing was thrown away.

The interface between biology and inanimate materials is often considered in terms of surgical systems and prosthetics and this was an important facet, Professor Miodownik said. People were going to be living longer, but they also wanted to be 'fully functioning' for longer as well. But there were opportunities for innovation in adapting biological materials for other purposes, such as bacteria that could help to 'heal' defects and degeneration in concrete.

> Bigger examples were needed of 'closed loops', where materials were fully recycled into new materials at the end of a product's life and nothing was thrown away

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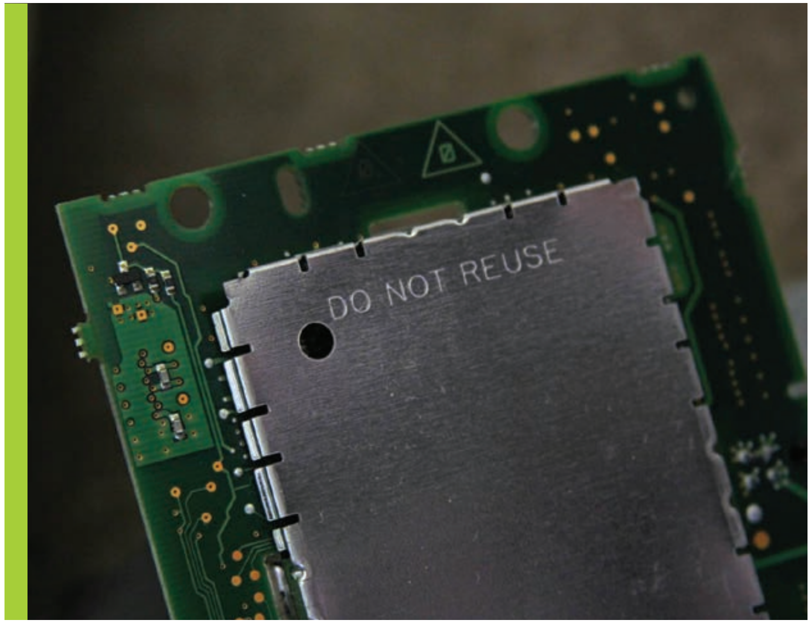


4. Innovation in materials and processes

Some of the challenges that Professor Mark Miodownik set down in his keynote address were taken up in the session that dealt with innovation in materials and processes. Much of the current research into materials is investigating the structure and properties of materials at the very small scale, and there is a high competition worldwide to translate the potential of materials such as graphene into real applications. At the same time, work on understanding the nature and properties of biological materials is enabling developments that combine the organic and inorganic, with potential benefits in areas much wider than just surgery and medicine. But the changes are not just about products: new materials are also feeding in to new methods of manufacturing that in turn benefit materials developments.

4.1 Size and scale: engineering at the atomic and at the gargantuan level

Graphene tends to take the headlines in nanomaterials, and there have been more than 7,000 patents taken out worldwide by researchers and developers working on it, said Dr Martin Kemp, Chairman of IOM3 nanomaterials committee. But graphene is just one of many nanomaterials under investigation worldwide: there are currently, for example, around 500 two-dimensional materials.

Part of the excitement, Dr Kemp said, was that at the nanoscale some of these materials exhibit physical and chemical properties that differ from those of larger particles: they interact with light, or they produce different chemical reactions. These properties may make them suitable for applications such as new kinds of solar cells or as catalysts fixing pollution in vehicle exhaust systems.

> Graphene, a material that was now ready to be made in serious amounts and with a very wide range of applications queuing up to take advantage of its physical properties: 200 times stronger than steel, conducts electricity better than copper and, as a sheet material, is impervious to gases

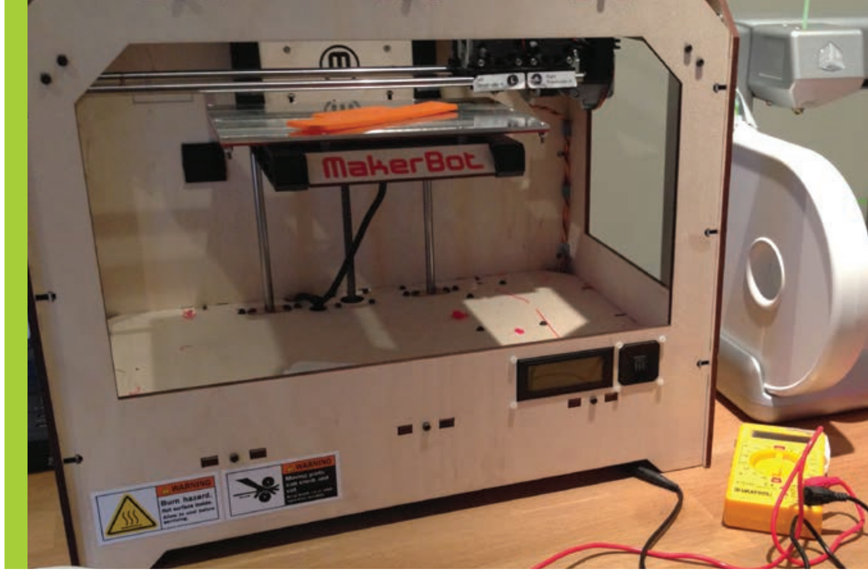
Graphene, however, is currently “the real deal”, Dr Kemp said, a material that was now ready to be made in serious amounts and with a very wide range of applications queuing up to take advantage of its physical properties: 200 times stronger than steel, conducts electricity better than copper and, as a sheet material, is impervious to gases. As a result, it is being put forward for a huge range of potential uses in electronics and sensors, as a barrier material to gases, exhibiting antimicrobial properties, in new kinds of solar cells and touch screens, and in batteries and catalysts. In this race to develop innovations that use graphene, the UK was doing very well, Dr Kemp said.

4.2 New ingredients: adding biology to chemistry in materials

Synthetic biology is the engineering of biology to build biological systems that display functions that are not found in nature and that are repeatable. Dr Tom Ellis, lead researcher at the EPSRC Centre for Synthetic Biology and Innovation at Imperial College London, said that the technology had reached a tipping point towards practical application through the work that had been done on DNA sequencing and through the lower cost of synthesis.

The engineering aspect in this is crucial and is what differentiates synthetic biology from the genetic engineering that has been done for 30 years, Dr Ellis said. Because the DNA codes are now better understood, desired effects can be reliably designed into biological systems over and over again: biological ‘manufacturing’ becomes possible when you can reliably predict and repeat the outcome. New codes can be introduced into organisms to get them to do things that are different or useful: an early experiment put the genetic code that produces light sensitivity in one bacterium into a different bacterium to enable the new host to detect the difference between light and dark. This is an example of where the biological code can be used as a form of on /off switch.

But synthetic biology opens up other possibilities that use DNA not just as ‘code’ but as a material in its own right. Dr Ellis cited work that has reprogrammed the genome in yeast and that looks to have promise in ‘growing’ chemicals including drugs and biofuels.



MakerBot consumer printer
© Econolyst

4.3 Manufacturing matters: how additive technologies change products

Additive manufacturing has achieved a degree of popular recognition through the hype surrounding 3D printing, although this is only part of a wider suite of technologies. For designers and manufacturers, the benefits are the ability to make structures, features and shapes that cannot be made by conventional manufacturing techniques and the potential to take advantage of different material properties from new formulations of original materials. So, for example, parts made from powder metals may be significantly lighter in weight than those made conventionally from solid metals by machining.

This, however, is only the start of the benefits that could come from these manufacturing technologies, said Professor Bill O’Neill from the Institute of Manufacturing at the University of Cambridge. The range of materials that can be applied using additive manufacturing is expanding, now taking in glass, ceramics and even elastomers.

With the extended range come other possibilities. Professor O’Neill cited current work on ‘growing’ prosthetic body implants to fit individual specifications, which is achieved by engineering specific features into the material to give new elements of control and new functions.

More than that, however, he said that additive technologies “enable us to change the way we think about materials”, by designing product function as well as form into the material itself. This is likely to lead to new types of ‘designer materials’ and even greater possibilities would be opened up when the manufacturing technologies broke free from the current additive two-dimensional layer-by-layer techniques to become truly three-dimensional, he said.

> Theft of metals such as lead and copper costs an estimated £220 million a year in the UK

5. Innovation in applications

The developments in materials science in terms of new properties, new formulations and new methods of manufacture open up a host of potential engineering innovations that promise to transform many aspects of current business and industrial products and systems. The conference heard presentations that explored four of these application areas that are already being exploited.

5.1 Tracking systems: materials for security

Theft of metals such as lead and copper costs an estimated £220 million a year in the UK, and the victims of crime are often august bodies and organisations – the Church of England, English Heritage, and the railway system, for example, lose roofs and wiring. The consequences are not just measured in financial terms and in inconvenience: there are safety implications in the theft of wiring for signalling systems.

Wire markings © Signature Materials

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The Signature Materials project led by the Institute of Materials, Minerals and Mining (IOM3) with the Pryor Marking Technology company was outlined by Dr Bernie Rickinson, chief executive of IOM3. Signature Materials has developed a system for permanently marking a wide range of structural materials in different forms such as sheet, tube and wire. The marked material is registered in a national database and can be instantly identified if it is recovered. There are plans to extend the scheme into new areas, such as battery materials.

5.2 Strength and weight: materials for aerostructures

The aerospace industry had long been a leader in the adoption of new materials, pioneering the use of lightweight metals such as aluminium and of composites. But the message that Dr John Haddock, head of the materials engineering discipline at BAE Systems, brought to the conference was that new materials in themselves were not the whole answer in the industry's constant quest for fuel efficiency and economy.

Many of the big gains in terms of weight saving through material substitution had already been made, he said, and the emphasis now was on production processes that would enable the next generation of benefits to be achieved on an industrial scale. "For every material development, there needs to be research into industrial processes to enable its use in practice," he said.

For new uses of composite materials within the industry, much of the current emphasis is on joining technologies, with developments in adhesives enabling a cut to be made in the numbers of fasteners, saving weight and need for parts. Fewer fasteners then meant that structures could have thinner skins, saving more weight.

This work, Dr Haddock said, required several developments, of which the material innovation in terms of paste adhesives was only one. It needed confidence that the joints created would be reliably strong and this came from automated surface preparation and analysis and from devising a consistent method for applying the adhesive; it also required systems and tools for inspecting the joints and for carrying out structural analysis. New materials were just the starting point, he said.

5.3 Harnessing power: materials for energy

Global energy provision is in need of a double revolution, and innovation in materials is probably the only way to achieve this, said Professor Ravi Silva FREng, head of the Advanced Technology Institute at the University of Surrey. Revolution number one is required because the global demand for energy keeps increasing year on year, and energy provision is the key to solving virtually all the other grand challenges of water, food, environmental pressures and poverty. And a second revolution is needed because currently 80 to 85 % of energy supply depends on fossil fuels and that is not sustainable in terms of resources or of the environment.

One answer, Professor Silva said, had to be greater use of solar power, which currently accounts for only 0.1 % of energy used worldwide. The sun provides around 165,000 Terawatts of potential energy each day, and global consumption now is between 10 and 15TW/day: even if a lot of the sun's energy is unusable – when it falls on the ocean, for example – and even if global energy demand quadruples by 2050, solar power provides an answer.

> The sun provides around 165,000 Terawatts of potential energy each day, and global consumption now is between 10 and 15TW/day

To achieve this, however, requires a leap-forward in technology. Where Professor Silva sees potential to solve this is in nanomaterials: the current solar photovoltaics industry is dominated by crystalline silicon at dimensions of 100µm. But new inorganic materials at a 100nm size could behave in the same way as single crystals and be applied in entirely new ways, such as in paints.

Cheap, readily available solar energy could also help to solve some of the energy sector's other technology conundrums, Professor Silva said. It might make electrolysis of water to produce hydrogen commercially viable, helping energy storage, for instance. Adventurousness in materials innovation could be key to solving big issues, he said: "There's an overwhelming need for innovation to drive the economics."

5.4 Inside the body: materials for medical and surgical use

Biomaterials used in human body repairs and surgery are a $45 billion market worldwide and as the average lifespan increases and demand grows for better quality of life in old age, so the market will expand. But biomaterials should not only be thought of as a technology for the elderly, said David Farrar, science manager for biomaterials at the medical devices group Smith & Nephew: applications such as fracture repairs and wound healing applied at all ages.

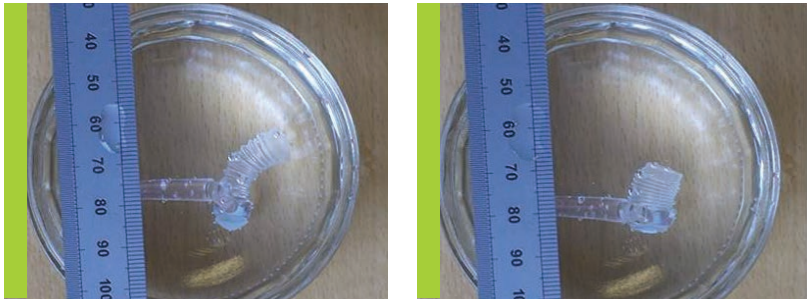
Mr Farrar outlined three stages in the evolution of biomaterials. The first stage, characterised by the earliest joint replacement implants, had seen biologically inert materials used, and whereas they had caused problems with wear and debris there were now improved formulations with surface treatments that promised 30 years of use.

The second stage of biomaterials had seen the development of bioresorbable polymers and was first exemplified by the polymer screws used to fix sutures and more recently by bone repairs. In these applications, there is now the use of shape memory polymers to provide better fit, Mr Farrar said.

A third generation of biomaterials goes further, however, and actively encourages healing through the delivery of drugs or by stimulating repair. Examples here include stents that release drugs to aid circulatory system repair and spinal fusion cages that contain bone proteins on a collagen sponge. There is a lot of potential, Mr Farrar said, for materials technologies such as nanoscale crystals and scaffolds to take this much further. "But the real potential is in entirely new materials," he said. These could include self-assembling peptides which might be injected into the body and then assemble themselves into a scaffold to help rebuild damaged tissue, bone or nerves.

This is innovation in materials but, he said, it linked across also into other areas of innovation – in the development of sensors and wireless communications for in-body monitoring, for example.

> But the real potential is in entirely new materials. These could include self-assembling peptides which might be injected into the body and then assemble themselves into a scaffold to help rebuild damaged tissue, bone or nerves



Shape memory polymer screw © Smith & Nephew

> The Great Recovery project aims to investigate the role of designers in a ‘circular economy’ where all products are designed for end-of-life disassembly and materials reuse

6. Innovation in market demands

Innovation in materials is driven by, and has impact on, broader economic and social trends, and topics touching on some of these aspects were highlighted in a brief panel discussion at the end of the Royal Academy of Engineering conference. The following section summarises some of the issues and ideas put forward.

Circular argument: closed-loop recycling

Sophie Thomas, co-director of design at the Royal Society of Arts, outlined the Great Recovery project which aims to investigate the role of designers in a ‘circular economy’ where all products are designed for end-of-life disassembly and materials reuse. Design, she said, was where 80 % of environmental cost was built into products, and many were designed for manufacture but not for disassembly or remanufacture. The project aims to map a circular network where product designers assume recovery rather than scrapping at the end of a project’s life and who therefore design for materials reuse.

See diagram opposite.

The Great Recovery Project’s Circular Economy uses new design networks to reduce waste. It explores how we should design products to eliminate waste. Creating products that work in a circular economy means avoiding products that use processes, composites or combine metals in ways that cannot be disassembled. With its expertise in design and manufacturing, the UK is well placed to create these cyclical systems
© Useful Simple Projects

Public and private: funding material research

Advanced materials represent one of the Great Eight Technologies that are seen as central to the UK government and the European Union research strategies, said Dr Robert Quarshie, director of the Materials Knowledge Transfer Network. Some of the aims of publicly funded research in this area included technology transfer between different applications and addressing issues in stimulating private and corporate investment. As in other technology sectors, there is a potential research funding gap between the proof of concept and the pre-production phase that government agencies and industry aim to bridge through the new Catapult centres and other mechanisms, such as the Innovation and Knowledge Centres co-funded by EPSRC and the Technology Strategy Board.

Evolving standards: measuring materials performance

Industries that fail to innovate are likely to disappear, said Dr Ben Sheridan, sector development manager for high value manufacturing within British Standards Instition. Dr Sheridan warned that material innovators needed to take account of the needs of the product designers who they hope will use their innovations: "Product designers will want evidence that the new idea works and is reliable and comes at the right price," he said. Potential users needed the reassurance that test methods and the application of international standards could provide, and innovators would be wise to engage with the standards process early in the development cycle.

Materials business: commercialising innovation

Richard Palmer, the founder of D3O Labs and developer of D3O 'intelligent' elastomeric material where the molecules lock together to absorb impact, advised would-be material innovators not to rely on just the measured, scientific approach in taking ideas to market. The ingredient that had led to his eventual success was not measurement: "It's about belief, and the right people who share it," he said. His material, a "dilatant polymer" used in outdoor clothing to be soft but protective, had failed to convince 300 potential investors in 18 months until he found financial backers who shared his belief in the product. He also found Spyder, a ski brand company that was prepared to test the material on Olympic athletes, not just in the lab. The results were very positive, and once the athletes believed in it, then everything really took off. He is now selling in 50 countries worldwide, has both manufacturers and retailers as his business partners, and the business continues to grow.

> It's about belief, and the right people who share it

7. Further information

1. **Signature Materials**
   www.signaturematerials.com
2. **IOM3 calls time on metal theft**
   www.iom3.org/news/iom3-call-time-metal-theft
3. **Signature Materials in Northampton**
   www.iom3.org/news/signature-materials-northampton
4. **Signature Materials surges forward**
   www.iom3.org/news/sigmat-electricitynorthwest
5. **Eight Great Technologies**
   www.policyexchange.org.uk/publications/category/item/eight-great-technologies
6. **Access to funding information**
   www.materialsktn.net
7. **European funding opportunities**
   ec.europa.eu/programmes/horizon2020/en/news/horizon-2020-launched-€15-billion-over-first-two-years

8. Acknowledgements

We would like to thank the following speakers for their contribution to *Innovation in materials*:

Chair

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Dr Tom Ellis
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Smith and Nephew

Dr John Haddock
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BAE Systems

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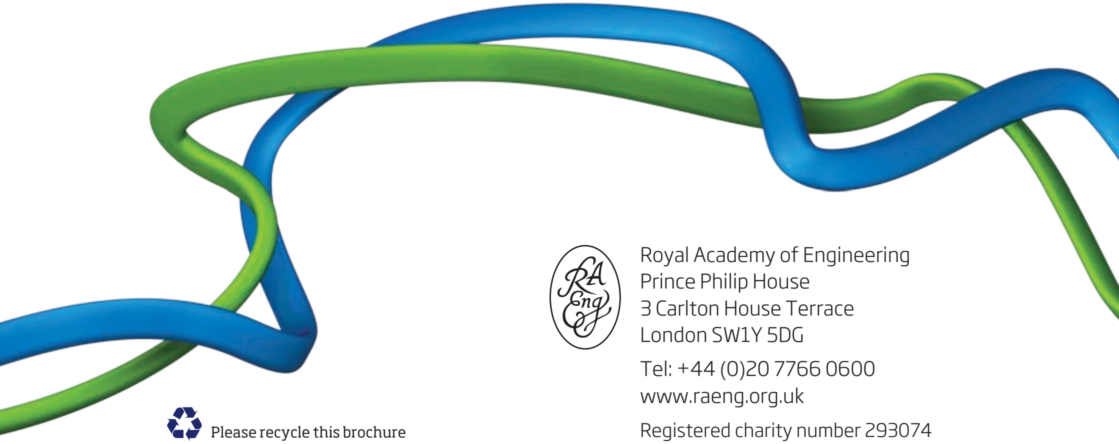

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