

TIME FOR STRATEGIC CHANGE: UK SURFACE ENGINEERING AND ADVANCED COATINGS INDUSTRY

A REPORT BY THE SEAC SPECIAL INTEREST GROUP



Special
Interest
Group

Surface Engineering
& Advanced Coatings

JUNE 2014

WHAT IS SURFACE ENGINEERING?

Surface engineering is all about modifying a surface for advantage. The term 'surface engineering' was promoted by Bell and Roberts in the 1980s, who defined it as: "The design of surface and substrate together as a functionally graded system to give a cost-effective performance enhancement of which neither is capable on its own."

The ASM Handbook Volume 5 "Surface Engineering" offers the following definition: "The treatment of the surface and near surface regions of a material to allow the surface to perform functions that are distinct from those functions demanded from the bulk of the material."

It is very important to consider the substrate, surface and their environment as a complete system rather than as individual entities.

In his report "2005 Revisited – The UK Surface Engineering Industry to 2010" Professor Allan Matthews identifies over 40 surface engineering and advanced coating processes, the main techniques are:

- Thermal spraying (including hardfacing, HVOF and cold spray technologies)
- Electrolytic and electro-less deposition processes
- Engineering paints (including organic and inorganic coatings, printing inks, powder coatings and vitreous enamelling)
- Physical vapour deposition coating processes
- Chemical vapour deposition processes
- Surface heat treatments
- Diffusion coatings (aluminising, chromising)
- Conversion coatings (anodising, phosphating, galvanising)
- Emerging technologies (e.g. electrophoretic deposition of thermal barrier coatings, laser deposition, molecular beam epitaxy, atomic layer epitaxy, atomic layer deposition and other nano-scale coating technologies)

ABOUT THE SURFACE ENGINEERING AND ADVANCED COATINGS SPECIAL INTEREST GROUP (SEAC SIG)

The Technology Strategy Board launched the Surface Engineering and Advanced Coatings Special Interest Group (SEAC SIG) in May 2013 with the aim of identifying specific areas where investment will help UK manufacturing realise the large market opportunities opened by the application of surface engineering and advanced coatings. The work of the SEAC SIG is led by the KTN with advice and steer by an Industrial Advisory Group with a strong academic representation.

Previous KTN reviews showed significant market opportunities in a number of key application sectors and demonstrated that the UK has considerable capability in terms of supply chain and technology provision. The Technology Strategy Board wanted the study to be extended to cover a much wider selection of market sectors and technology areas in order to clearly identify the strategic technology and innovation priorities for the UK.

The ultimate aim of the SEAC SIG is to assist the UK in its investment decisions in addressing technology and innovation gaps and to help accelerate commercialisation of new technologies in the SEAC area.

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EXECUTIVE SUMMARY

The Technology Strategy Board report on the future of high value manufacturing identifies “Development and Applications of Advanced Coatings” as a National Competency under the strategic theme “Creating innovative products through integration with new manufacturing technology”.

The Surface Engineering and Advanced Coatings Special Interest Group (SEAC SIG) community has created an £11bn business, which plays a key role in producing over £140bn of products. The market has grown year on year. There is an active culture of innovation developing new products and processes to benefit sectors as diverse as aerospace, automotive, healthcare and the built environment. SEAC technologies often provide an effective solution where other approaches fail. Users need SEAC technology to enhance product performance, exploit efficient materials utilisation and adapt to changes in the business environment. Innovation plays a vital part in their products and has created competitive advantage, for example:

- For aerospace/energy ... thermal barrier coatings
- For built environment ... self cleaning systems and solar energy
- For medical ... orthopaedic implants

The first Community Engagement Workshop, held on 17 July 2013 at the Institute of Materials, Minerals and Mining in London, gathered together key UK researchers and industrialists in SEAC to identify:

- The capacity and capability of UK technology providers and other supply chain members and their R&D activities
- Market opportunities for SEAC technologies
- Drivers for change and barriers
- The position of the UK SEAC sector within the

global market

In addition to inputs from this initial workshop the project team developed a series of questionnaires that were used to survey the views of other UK researchers, supply chain players and end-users. A strategic workshop was held in January 2014 at the Manufacturing Technology Centre in Coventry to explore emerging issues around repositioning SEAC technologies to:

- Maximise the value from innovation in SEAC technology
- Enable the SEAC supply chain to become a strategic element of high value manufacturing
- Develop the SEAC supply chain to be competitive through the product life cycle

The findings confirmed that the UK has the potential to provide a full supply chain for Surface Engineering and Advanced Coatings (SEAC) technology with a major end-user presence supported by suppliers of world-class products and services and researchers. The sector finds that strong end users, who create and drive their supply chains, are the most effective model in developing a proactive and innovative culture. However, in interviews, end users cited low confidence in the long-term performance of both coatings and their processing as a barrier to the introduction of new products dependent on surface engineering and advanced coatings. Developing approaches to designing quality into both components and processes would advance this approach and develop significant global markets through increased confidence in SEAC technology.

This SEAC SIG study has highlighted the many strengths of the UK in surface engineering and advanced coatings. As one of the national competencies in high value manufacturing, the SEAC

community has created a major and expanding supplier industry. Its products are vitally important to all of the UK's manufacturing sectors and are able to change market dynamics enabling disruptive technologies in a diverse range of products such as gas turbine engines, drill bits, architectural glass and orthopaedic implants.

An active innovation culture has enabled the SEAC sector to be internationally competitive. The community has built strong, long-term contacts between the research base and industry, which are particularly effective when supportive and strong end users create and drive the supply chain and R&D programmes. They recognise that SEAC technology is able to address many of the problems and development issues faced by industry.

The study has also highlighted that suppliers need to develop their capabilities further if they are to provide the required service and confidence to customers in high value manufacturing sectors.

Initiatives to raise the confidence and understanding of potential customers in SEAC technologies and the capability of the supply chain should address:

- Raising awareness and accessing preproduction facilities and capabilities
- Increasing proactivity to address industry wide issues
- Moving to predictive design of coatings within systems
- Enabling consideration of surface engineering as a strategic manufacturing process

The following recommendations are made to address certain vulnerabilities and to catapult the UK SEAC supply chain to fully embrace 21st Century high value manufacturing principles:

1. SEAC supply chain to establish a Leadership Forum for surface engineering and advanced coatings
2. SEAC to become a strategic process aligned with high value manufacturing principles
3. SEAC supply chain to embrace design for manufacture
4. Easy access to facilities and means of building manufacturing capability and capacity
5. Improve awareness of SEAC technologies and processes across all UK manufacturing sectors
6. Increase proactivity within the SEAC supply chain

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1. INTRODUCTION

The way the surface of a product is treated can help improve the functionality and performance of an equipment or product. It helps to make the surface corrosion resistant, wear-resistant or enable it to withstand high temperatures, provide antifouling or antimicrobial properties or even turn a benign surface into a smart material or product that senses and reacts to external stimulus. Advances in cosmetics and cosmetic surgery are made possible by the same surface science and technology that underpin surface engineering.

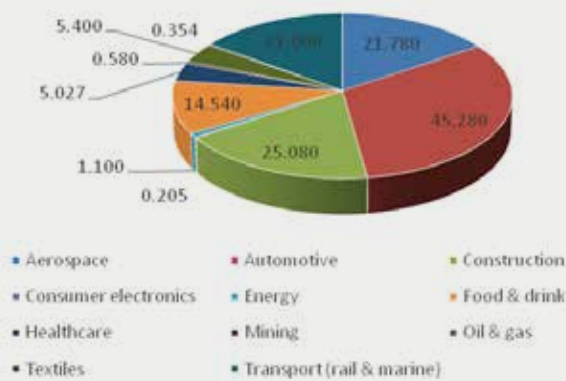
Surface engineering and advanced coatings are used right across the spectrum of manufacturing and engineering industries to enhance the surfaces of components that can be made from low-cost, lightweight or sustainable materials. This allows the designer to create cost-effective, high-performance parts with a functional surface exactly where it is required. These are often enabling disruptive technologies in a diverse range of products such as gas turbine engines, drill bits, architectural glass and orthopaedic implants.

Surface engineering and advanced coatings are used to give a predictable extension of in-service lifetime or to provide properties that the untreated substrate does not possess for more efficient performance in a particular application.

Surface engineering and advanced coatings are used to impart many characteristics to components, the main ones being:

- Wear resistance
- Corrosion resistance
- Heat resistance
- Oxidation resistance
- Electrical resistance
- Electrical conductance
- Fatigue strength
- Restoration of size
- Clearance control
- Self-healing
- Self-lubrication
- Self-cleaning
- Non stick
- Water repellent
- Anti-microbial
- Bio-compatible
- Bio-active
- Brazing
- Catalyst
- Diffusion barrier
- High absorption

Value of Products affected by SEAC (Ebn)



Surface engineering and advanced coatings (SEAC) allow scarce and strategic materials or materials affected by legislation to be substituted with more sustainable and environmentally friendly materials. The effective use of SEAC technologies has been identified by the Technology Strategy Board as one of the national competencies needed for the future development of High Value Manufacturing.¹ This is because of the critical enabling nature of the technologies and industrial applications involved. SEAC technologies underpin every industrial, engineering and manufacturing process and have proved critical in realising policy agenda that promotes reduced dependency on scarce materials, low carbon and energy efficient economy and sustainable manufacturing. The criticality of SEAC technologies to the UK is shown by their major market impact and this impact continues to expand significantly.

The UK's engineering coatings industry is worth over £11bn and affects products worth £140bn.²

Owing to the finishing nature of SEAC technologies there is a temptation in many cases to see their adoption as an 'add-on' or 'afterthought' option that can enhance product performance. However, this view seriously undersells their value and produces inefficiencies in UK manufacturing processes.

There are many examples where SEAC technologies have been key to disruptive product development or where their application has translated over time from being an 'optional' extra into an essential market qualifier. The evolution of the cutting tool illustrates the powerful changes that SEAC technologies can impart on a product's lifecycle and market acceptability. The disruptive nature of SEAC technologies for both products and markets, their ability to breathe new life into used products, create distinctive properties for products and become the platform for radical innovations leading to brand-new applications and business models, convinced the Technology Strategy Board to commission the KTN to set up the SEAC Special Interest Group to identify the technology and innovation needs of the industry and how best to address these. In particular, as a key competency for UK manufacturing, there was a need to look at how SEAC technologies align with the principles of high value manufacturing.

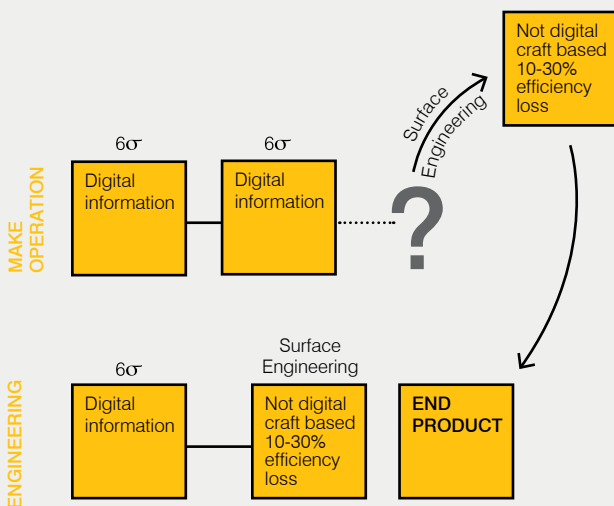


Figure 2: Vulnerability in UK surface engineering and advanced coating processes due to the 'digital gap'

¹ High Value Manufacturing Strategy 2012 - 2015, Technology Strategy Board

² R J Artley and A Matthews, "The UK Surface Engineering Industry 2010". Report Sponsor: Surface Engineering Association, 2010, ISBN 978-0-9567041-0-8

CASE STUDY A

AUTOSPORT DRIVING COATINGS DEVELOPMENT



Source: Wallwork
Cambridge - a piston
and two TiN coated

High technology coating of autosport components allow race engines to run hotter, faster with increased stresses and lower frictional losses. Without such coatings many modern bespoke racing engines simply will not function optimally.

Key reasons for coating racing engine components are;

- Prevention of corrosion
- Reduction of wear
- Improving the coefficient of friction
- Improving materials compatibility
- Modification of other material problems

The effects of abrasive, adhesive and fretting wear as well as surface fatigue can be mitigated by the use of coatings whether on one or both counter facing surfaces.

Coatings are used in a range of environments inside and outside of the engine. Exposure to high temperatures, thermal cycling, high sliding velocities, high contact stresses and amplitudes, immersion in water, fuels and oils all affect the coating. Consequently it is vital that the designer considers not only the primary duty of the coating but also the rigours of the environment it operates within.

Companies developing new variants of coatings for the autosport sector must provide R and D capability with an in-house team of engineers and scientists and extensive and well equipped laboratory. One such coating, Nitron O developed by Wallwork Cambridge, has been designed for the enhancement of Titanium alloys by a novel duplex process and is seen as a significant step towards the development of lighter more powerful engines.

Designers within the racing industry want greater power, greater longevity and more highly loaded components and see the key driving forces of automotive engine coating development as;

- Lower friction
- Greater reliability
- Greater load capacity
- Lower part cost

All of these drivers are the same within series-production engines and this is one area where racing engine manufacturers are leading series-production vehicle manufacturers to a lower friction future. Within a few years we will see relatively low cost cars fitted with coated valve train components and, where autosport's goal is enhanced performance via lower friction, theirs is lower fuel consumption and emissions also via increased lubricity.



The Trent 900 powers the Airbus A380



Rolls-Royce has sold nearly 500 units to the offshore market in 30 countries for use on platforms and FPSOs



Source: Wallwork Cambridge - a clutch basket

The industry itself has been concerned about the vulnerabilities created by a fragmented supply chain, the low barrier to entry of new applicators, lack of pull through of major breakthrough technologies and the lack of concentration of R&D effort.

SEAC FACILITIES

There is a perception that the UK suffers from a lack of SEAC facilities suitable for pre-production and this point was raised at the community engagement workshop. However, on investigation, the UK SEAC supply chain does have a wide range of facilities that can be used for processing prototype components, especially for the major processes such as thermal spraying, PVD, CVD and electroplating. In some facilities the size and geometry of components can be a limiting factor, but in some cases even large components such as paper mill or printing rolls can be accommodated.

A recent survey of SEAC facilities in some universities and RTOs has shown that there are a number that can be used for pre-production, but perhaps size and geometry of components is a greater limiting factor than in the SEAC supply chain.

The UK supply chain for SEAC technologies has already created an impressive and internationally competitive track record of innovation. However, the need to ensure growth in UK high value manufacturing supported by a highly efficient and sustainable SEAC supply chain encouraged the SEAC SIG to look at opportunities for the industry to maximise benefits from all its innovations and be integrated with and aligned to the design and digital manufacturing processes used by its customers.

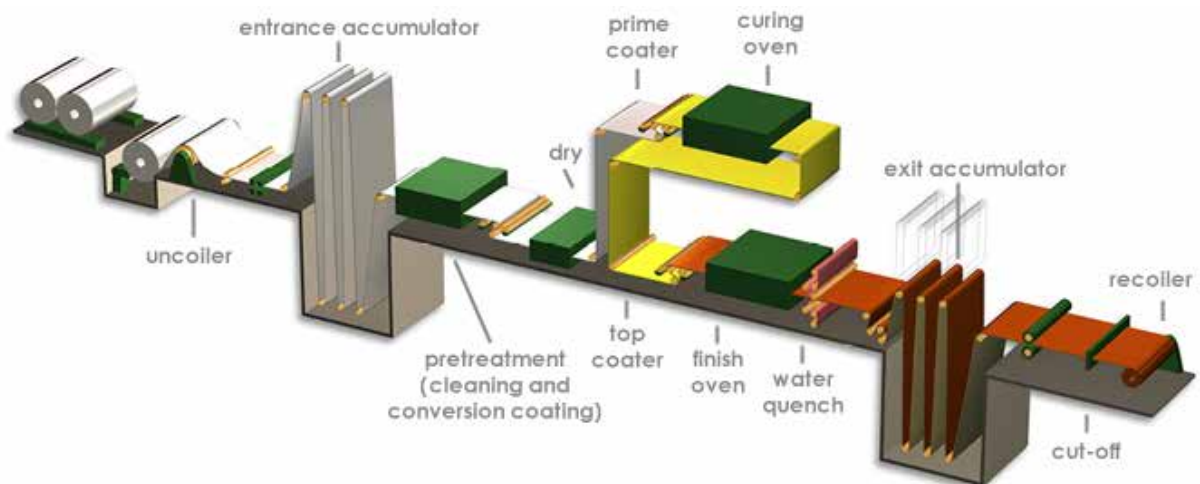
This report details the analysis of the findings from 12 months of study working closely with a cross-section of the SEAC supply chain and end users. The analysis has led to a number of recommendations, priority actions and essential enablers to ensure the UK takes a leading position in SEAC technologies to sustain our growing high value manufacturing activities.

CASE STUDY B

COIL COATING – AN EXAMPLE OF HIGH VALUE MANUFACTURING PROCESS

Coil coating is a continuous and highly automated process for coating metal before fabrication. In one continuous process, a coil of metal, up to 2m wide moving up to 250m per minute, is unwound and both the top and bottom sides are cleaned, chemically treated, primed, oven cured, top coated, oven cured again, rewound and packaged for shipment. More specifically, bare coils of metal are placed on an unwinder or decoiler where the metal is observed for defects. The metal is then cleaned and chemically treated in preparation for painting. Brushes can be used to physically remove contaminants from the sheet. Pretreatments may be used to provide the bond between the metal and the coating, and as extra protection against corrosion. After drying, the strip enters a coating room for a coat of primer usually on both sides of the sheet. The pickup roll transfers the coating liquid from the pan to the applicator roll. The liquid is then pumped into the pan, and then

overflows back to the supply reservoir, where it is remixed and filtered. The direction of the rotation of the applicator roll plays a part in determining the type of coating. Reverse roller coating, when the applicator roll turns in the opposite direction of the strip, is used to apply thick coatings. Direct roller coating, turning in the same direction to the strip, is used for thinner coatings. Coil coating provides for controls that are virtually impossible to attain with most other painting processes. Dealing with a flat sheet allows for mechanical cleaning in addition to the spray cleaning. The flat sheet also enables excellent control of coating weights of both the pretreatment and the paint to within a tenth of a mil or less, depending upon the equipment and the paint system being applied. Such advantages, along with the economic and environmental benefits, make coil coating an excellent example of where the SEAC industry has embraced the principles of high value manufacturing.



Source: National Coil Coating Association

2. THE VITAL IMPORTANCE OF SURFACE ENGINEERING AND ADVANCED COATINGS

Surface Engineering and Advanced Coatings (SEAC) technologies are selected to enhance surface properties, add functionality to products and bring business opportunities. They are used by most industrial and manufacturing sectors, which see them as vital to the success of their products, creating new markets and meeting customer demands.

CASE STUDY C

COATINGS PROLONG BEARING LIFE IN HARSH ENVIRONMENTS

Often, operating conditions exist that are beyond the limits of standard bearings. However, by applying a coating or combination of coatings to the base material of bearing components, the operating life of the bearings can be extended significantly and it is often necessary for bearing manufacturers to offer customers unique combinations of coatings for particular applications.

Many different types of coatings are available, which can be applied using a variety of methods and which offer a wide range of advantages for the component; customer satisfaction depends on the expertise of the supplier:

- If problems of corrosion, wear or the passage of electric current are expected, coatings are normally applied to the base material of bearing components. The coating is typically applied to the surfaces of components without thermo-chemical diffusion taking place between the coating and the base material.
- Corrosion or fretting corrosion can be prevented by applying a zinc-iron alloy or zinc-nickel coating to the bearing components. If increased corrosion protection is required, for example, for automotive components or for large bearings in steel rolling mills, a zinc-iron alloy coating with passivation or chromating can be applied.
- For high quality cathodic anti-corrosion protection, zinc-nickel alloys with thick layer passivation (or electroplated layer) can be used.
- For even higher levels of anti-corrosion protection, zinc lamellar coatings can be used.
- Dark grey or black in colour, PTFE coatings are used to improve the sliding capacity of the bearing outer ring. Application examples include main rotor bearings on wind turbines and spherical roller bearings for cement mills and paper mills.
- If the bearings need to be insulated from the passage of electric current, oxide ceramic coatings can be applied. These normally take the form of a ceramic coating comprising aluminium oxide with sealant. Typical applications include bearings in three phase motors, traction motor bearings, wheelset bearings, and bearings for wind turbine generators.
- For surfaces that are subjected to high tribological stresses with lubricant starvation, carbon coatings can be used. These hard, amorphous, non-metallic hydrocarbon coatings are typically 2-4 μm thick and offer improvements in friction reduction by up to 85 per cent compared to steel/steel.

Courtesy: SCHAEFFLER (UK) LTD, SUTTON COLDFIELD

Although sectors have specific requirements and operating conditions, interviewing revealed common drivers to the adoption of SEAC technologies.

At the most basic level, their application will improve product performance.

However, appropriate use can bring more extensive competitive advantage, for example:

- Enabling disruptive technologies and products: even though an established SEAC technology may not be disruptive in itself, its use can often enable technologies and products that are disruptive.
- Stimulating new market opportunities, where the application of a SEAC solution allows the manufacture of a product that could not be made in any other way.
- Differentiating products in crowded markets.
- Providing an essential market qualifier: the eventual extension of the performance benefit to the point where it becomes an essential requirement and any supplier that has not embraced the SEAC solution will have disappeared from the market place.
- Enhancing resource efficiency: more sustainable processes are possible through reduced use of raw materials and energy, and the elimination or reduction of scarce materials (or those with security of supply concerns). SEAC can also facilitate the remanufacture of worn or mis-machined components to restore the original size.

Examples of all of the above benefits include:

- The use of Electron Beam Physical Vapour Deposition (EB-PVD) to apply more effective thermal barrier coatings to gas turbine components to improve cooling and allow higher operating temperatures (and hence improved engine efficiency)
- Physical Vapour Deposited (PVD) coatings on cutting tools
- Roll-to-roll coil coating processes to produce high-speed, high-performance coated products
- Coatings on fuel injector components to enhance durability and enable the deployment of common-rail fuel injection systems in high-performance diesel engine designs
- Abradable coatings in gas turbine engines
- Self-cleaning window glass
- Porous coatings on orthopaedic implants to encourage osteo-integration
- Functional coatings to turn buildings into power stations
- Antifouling coatings for marine applications

3. MARKET SIZE

The importance of surface engineering and advanced coatings is very clear from the size of the market, especially the value of products affected by SEAC and the turnover of the companies making them. An updated estimate carried out for this study values the UK-based engineering coatings industry at over £11bn and affecting products worth £140bn.

The market has also shown sustained growth over the last 20 years. In the report, “2005 Revisited – The UK Surface Engineering Industry to 2010”, Professor Allan Matthews et al concluded that the UK market for surface engineering for wear and corrosion protection was £4.5bn in 1995 and affected manufactured products worth £95.5bn.³

By 2005 the engineering coatings market was predicted to be £7bn in engineering applications and affecting

manufactured products worth £117.3bn.

Artley and Matthews in their report for the Surface Engineering Association “The UK Surface Industry [in] 2010”, showed that the engineering coatings industry was worth £10.8bn and affecting products worth just over £140bn.

Harrison and Matthews have updated the figures to current values finding a slight increase in the value of the SEAC market over the last two years, with the value of the products affected remaining much the same. These figures corroborate those of previous reports and add an interesting comment on the turnover of the companies whose products are affected by surface engineering and advanced coatings.

Sector	Year	Turnover (£bn)	Total SEAC Market (£bn)	Value of SEAC multiplier	% of products affected by SEAC	Value of Products affected by SEAC (£bn)	Source
Aerospace	2011	24.20	0.980	22.2	90.0	21.780	ADS figures
Automotive	2011	56.60	2.000	22.6	80.0	45.280	SMMT figures
Construction	2012	83.60	3.000	8.4	30.0	25.080	Construction stats No 14 for Parliamentary briefing
Consumer electronics	2012	2.05	0.200	1.0	10.0	0.205	Ibis World
Energy	2011	11.0	0.550	2.0	10.0	1.100	DECC figures
Food & drink	2009	72.70	0.727	20.0	20.0	14.540	fdf report
Healthcare	2012	50.27	0.250	20.1	10.0	5.027	BIS report: Strength & Opportunity 2012
Mining	2011	2.90	0.050	11.6	20.0	0.580	MineralsUK – UK Minerals statistics
Oil & gas	2012	27.00	2.700	2.0	20.0	5.400	Oil & Gas UK
Textiles	2012	17.70	0.050	7.1	2.0	0.354	Tutor2u
Transport (rail & marine)	2012	35.00	0.700	30.0	60.0	21.000	ORR, UK Marine alliance
Totals	-	383.02	11.21	-	-	140.346	-

³2005 Revisited – The UK Surface Engineering Industry to 2010, Matthews et al



Moreover, these studies have revealed that surface engineering and advanced coatings are particularly important in safety-critical sectors (such as energy and mining) and in sectors in which coatings directly influence product performance and efficiency (e.g. aerospace and automotive), meaning that SEAC technologies are vital to the competitive position of companies in those sectors. Appendix A details examples of sector opportunities available to the SEAC supply chain.

This study has concentrated on the engineering coatings applications sectors. SEAC technologies also have a significant presence in the manufacture of electronic devices with an estimated market of £14bn and an effect on products worth £25bn.

CASE STUDY D

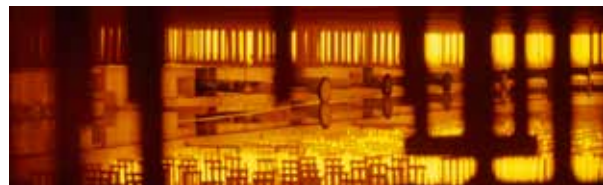
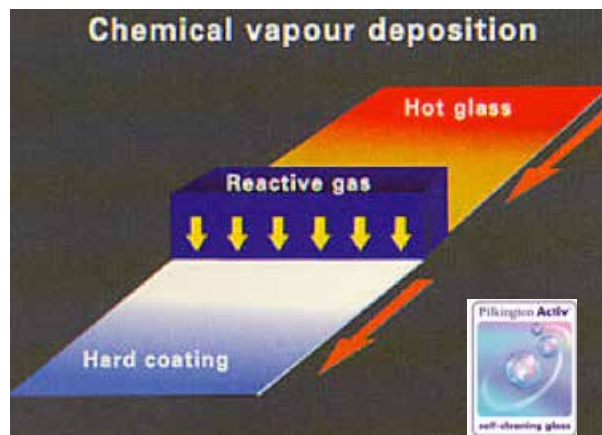
FUNCTIONAL COATINGS ON GLASS

By improving performance and adding functionality, coatings on glass add significant value to many glazing products. Adding colour, limiting heat transmission, enhancing reflectivity and improving self cleaning properties are a few of the characteristics that glass can be endowed with by engineering surfaces and interfaces through the application of advanced thin films.

In recent years the capability to apply a controlled TiO_2 based film via a Chemical Vapour Deposition process on a glass production float line to enable self cleaning properties through surface modification has resulted in significant take up of Pilkington Aktiv™ glass, the first example of its class to be fully commercialised following years of research with leading UK Universities.

The self cleaning process that occurs at the glass surface involves two stages that employ first photocatalysis and second hydrophobicity to enable dirt removal. In more detail, sunlight activates the surface causing the organic material present on the window to be chemically broken down thus loosening it. Subsequent wetting of the window by rain or other water sources is spread evenly over the hydrophilic surface such that residual dirt is washed away more effectively.

The use of the coating can result in significant savings in cleaning maintenance and has applications in architectural and solar cell fields. The demand for self cleaning products is driving a rising market for flat glass products with growth of ~8% pa predicted to 2017.



CASE STUDY E

FOULING CONTROL COATINGS FOR MARINE APPLICATIONS

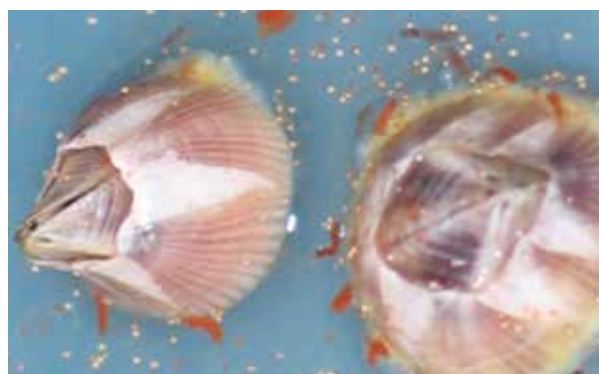
Marine biofouling, the unwanted colonization of marine organisms on surfaces immersed in the aquatic environment, has a huge impact in terms of increased maintenance requirements for marine structures and an increase in hull roughness leading to increased drag, fuel consumption, and consequent greenhouse gas emissions in the marine shipping industry. In the latter case for example, it is widely accepted that a fouled hull can be estimated as correlating to an increase in fuel consumption of 40%. According to a more recent US navy study however, the penalty can be as high as 86%¹. Given that the average cargo ship consumes around 300 tonnes or \$150,000 worth of fuel per day², then the economic consequences are clear.

Effective fouling control is therefore a pre-requisite in order to maintain the efficient operation of any mobile or static structure deployed in the marine environment. The majority of fouling control coatings rely on the release of biocidal chemical actives in order to achieve inhibition of biofouling. The most advanced biocidal antifouling coatings are based on so called self or linear polishing technologies. These systems facilitate the sustained delivery of the biocidal active by virtue of a seawater mediated hydrolysis or exchange reaction which renders the coating soluble at the seawater interface. This results in the continuous release of both biocide and binder constituents from the surface of the coating into the seawater over the duration of the coating lifetime (typically specified as 5-7 years).

Fouling release coatings provide an effective alternative to biocidal systems and are based on polymers which minimize the molecular adhesive forces between the coating surface and the natural adhesives excreted by the marine organisms. As a result of the weakened interaction, adhered

organisms are easily released by the hydrodynamic shear forces resulting from vessel activity. The latest fluoropolymer based coating systems are for example capable of releasing marine biofilm or "slime", through vessel movement even at low speeds.

As is demonstrated by the recently launched Intercept® and award winning Intersleek® ranges, AkzoNobel is at the forefront of innovation in fouling control technology. Furthermore, the development of these new products serves to highlight AkzoNobel's commitment to open innovation with collaborative research between in-house development teams, leading UK universities and complementary global expertise networks, being an integral part of the development process.



¹ Schultz et al., Biofouling 27, 87-98 (2011)

² Protective Coatings, Jan-March, 2-7 (2013)

4. INDUSTRY STRUCTURE AND BARRIERS TO INNOVATION

The UK has the potential to provide a full supply chain for Surface Engineering and Advanced Coatings technology with a large end-user presence supported by suppliers of a wide range of products and services and an active research base. UK-based suppliers provide services that underpin virtually every manufactured product.

This SEAC community finds that strong end users create and drive their supply chains and are the most effective model for developing a proactive and innovative culture. However, UK product manufacturers are not maximising the benefits that could be gained from SEAC technologies with companies citing low confidence and uncertainty in the effectiveness of SEAC technologies as significant barriers to innovation. The wide range of SEAC technologies developed to address an ever-expanding list of potential uses has led to a fragmented supply chain which is exacerbating the situation further through poor information flow.

The barriers to wider SEAC innovation include:

- Low level of understanding of SEAC technologies and their implementation, found in many companies, which creates uncertainty about who can provide particular technologies and has pre-production facilities.
- Uncertainty in the long-term performance of coatings; coatings are designed often for long service lives. Accelerated testing in simulated conditions frequently does not reflect the true service exposure. There is not a culture of data sharing as test data generated by/for companies are seen as important intellectual property by many of them.
- High financial risk through poor cost-benefit analysis over the short term when introducing SEAC technology, which often requires the purchase of relatively expensive equipment, and complex as well as costly qualification processes for heavily regulated markets such as aerospace and healthcare.
- Lack of standards to help customers specify and test products, which leads to poorly defined requirements. Standards were developed many years ago, often for defence purposes, and they have not been maintained.
- Many skills-based processes rather than machine-controlled ones mean companies must recruit or train staff when introducing processes and cannot adopt automated process control strategies and quality cannot be fully verified by non-destructive inspection
- Complicated or absent recycling strategies for coated products as the coatings may be required to be separated from the base material.



UK suppliers of technology thought themselves to be generally internationally competitive, with some weak areas, for example some speciality coating chemicals are not available from UK suppliers. However, their customers, the users of SEAC technology, rated the supply chain as either competitive or five years behind overseas companies. They also highlighted that providers of SEAC technology have yet to embrace the digital age and give the perception that the supply chain is inward looking and conservative rather than proactive to industry needs. They observed that suppliers would have greater competitive advantage if they align SEAC technologies to the strategic imperatives of high value manufacturing to reduce their vulnerability to customers moving to overseas suppliers or new market entrants.

A stakeholder workshop organised by the SEAC SIG explored three issues around repositioning SEAC technologies to:

- Maximise the value from innovation in SEAC technology
- Enable the SEAC supply chain to become a strategic element of high value manufacturing;
- Develop the SEAC supply chain to be competitive through the product life cycle.

The workshop identified actions that could be grouped into five themes. These are explored in greater detail later in this report.

THEMES

- Improved awareness
- Becoming a strategic process
- Better design approaches
- Access to facilities and capabilities
- Increasing proactivity

5. VIEW OF THE INNOVATION SCENE

Innovation and new technology help the sector maintain its competitive position. The UK research base has strong, long-term, industrial contacts and international links, which have led to an active innovation culture. Supply companies need technology that is applicable in many different applications and readily transferred to different sectors, to remain competitive. End users need to exploit the benefits from SEAC technology to enhance product performance, exploit efficient materials utilisation and adapt to changes in the business environment.

The SEAC community is making effective use of the current support for collaborative R&D with over 550 projects supported in the last decade. These were identified by searching on “Surface Coating” in web-based databases.

	TOTAL	ACTIVE	CLOSED
EPSRC	186	82	104
TSB	60	26	34
FP	320	239	81

Number of SEAC projects supported over the last ten years



	EPSRC	FP	TSB	CURRENT MARKET SHARE
Paints	18%	24%	12%	35%
Chemical vapour deposition*	17%	13%	10%	0.80%
Molecular beam epitaxy	14%	14%	0%	-
Sputtering	12%	11%	0%	-
Electrophoretic deposition	9%	0%	0%	-
Vitreous enamel	7%	0%	0%	1.30%
PVD*	1%	3%	30%	0.80%
Laser spraying	0%	4%	12%	3.50%
Laser deposition	7%	5%	0%	-
Electrolytic deposition / electroplating	6%	5%	7%	23.60%
Others	9%	21%	29%	

Results of web search publicity funded SEAC projects over the last ten years

Technology Readiness Level (TRL)	1	2	3	4	5	6	7	8	9	
Activity	Discovery & Research		Innovation					Commercialisation		
TRL Description	Basic principles observed and reported	Concept of application formulated	Experimental proof of concept	Concept or process validated in laboratory	System or component validated in relevant environment	System model or demonstrator in relevant environment	System prototyping demonstrator in an operational environment	Actual system completed and qualified test & demo operational environment	Actual system mission-proven in successful mission operation	

Definition of the TSB accepted Technology Readiness Level scale

With activities judged to be in Technology Readiness Levels 1 to 7, the projects covered each innovation type: step change development, evolutionary development and enabling technology development.

Much of the research is into emerging processes rather than established processes.

Surface engineering approaches should continue to be included in the scope of calls for collaborative R&D proposals as the SEAC community is able to offer potential viable solutions to many problems and development issues faced by industry. It is worth noting that the use of established surface engineering and advanced coating technologies in new application areas often enable disruptive innovation and have the potential to open significant new market opportunities.

6. INTERNATIONAL BENCHMARKING

Firm data on the UK's international competitiveness in developing and commercialising SEAC solutions has proved difficult to access. In relation to the UK's technology development activities, at least in a pan-European context, the most readily accessible information in the public domain relates to UK participation in EC-funded research projects. This has been defined by interrogating the EC's on-line project database⁴ and the conclusions drawn are outlined below.

When it comes to issues that relate to the translation of research activity into commercial innovation it has proved possible to compare the conclusions drawn from consultations with UK stakeholders in this study with published reports from a number of international competing countries. These issues are also explored below.

6.1 UK INTERNATIONAL COMPETITIVENESS IN RESEARCH ACTIVITY

The following broad conclusions can be drawn from the analysis of the information obtained on SEAC-related projects in EC Framework Programmes 6 and 7:

- The UK has been the single most active member state in leading SEAC projects in FP6 and 7 programmes.
- The major competing countries by this measure are: Spain, Italy, Germany and France.
- Other countries, which have led at least 10 projects across the two framework programmes, are: Belgium, Netherlands, Switzerland, Austria, Greece, Sweden, Denmark, Ireland and Finland.
- In relation to activity on specific SEAC technologies (particularly emerging technologies), there are some clear 'centres of expertise' in countries on this secondary list. For instance, for Atomic Layer Deposition, the Netherlands, Belgium and Switzerland are all more active than any of the 'big 5'.

6.2 INTERNATIONAL COMPARISONS ON INNOVATION ISSUES

Earlier sections of this report have identified the views of UK SEAC stakeholders on the current status of the industry and technical solutions, the perceived barriers to innovation and the drivers that might stimulate more effective innovation.

It has been possible to compare these views with published reports from a number of leading competing nations, with the overall conclusion being that these countries face similar issues to the UK albeit with local variations.

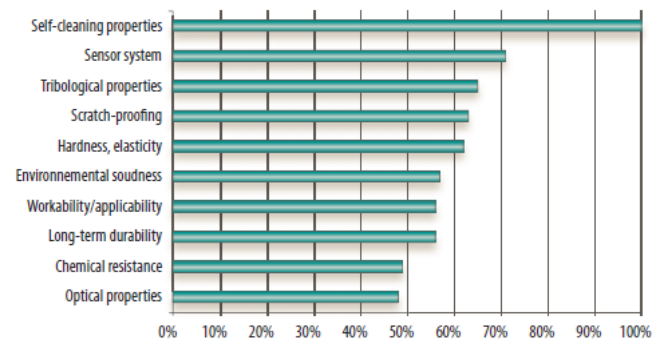


Figure 3: Importance of technological trends in surface technology (100% - mentioned by all respondents)

In **Germany** a recent report has highlighted the surface properties identified by companies and institutes as being needed for the future (Fig. 3). Delivery of these properties is viewed as having the potential to provide a competitive edge.

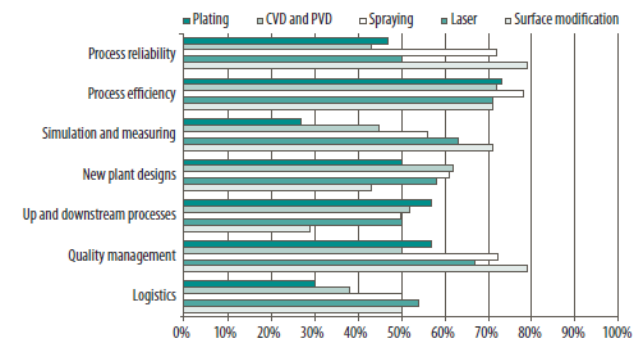


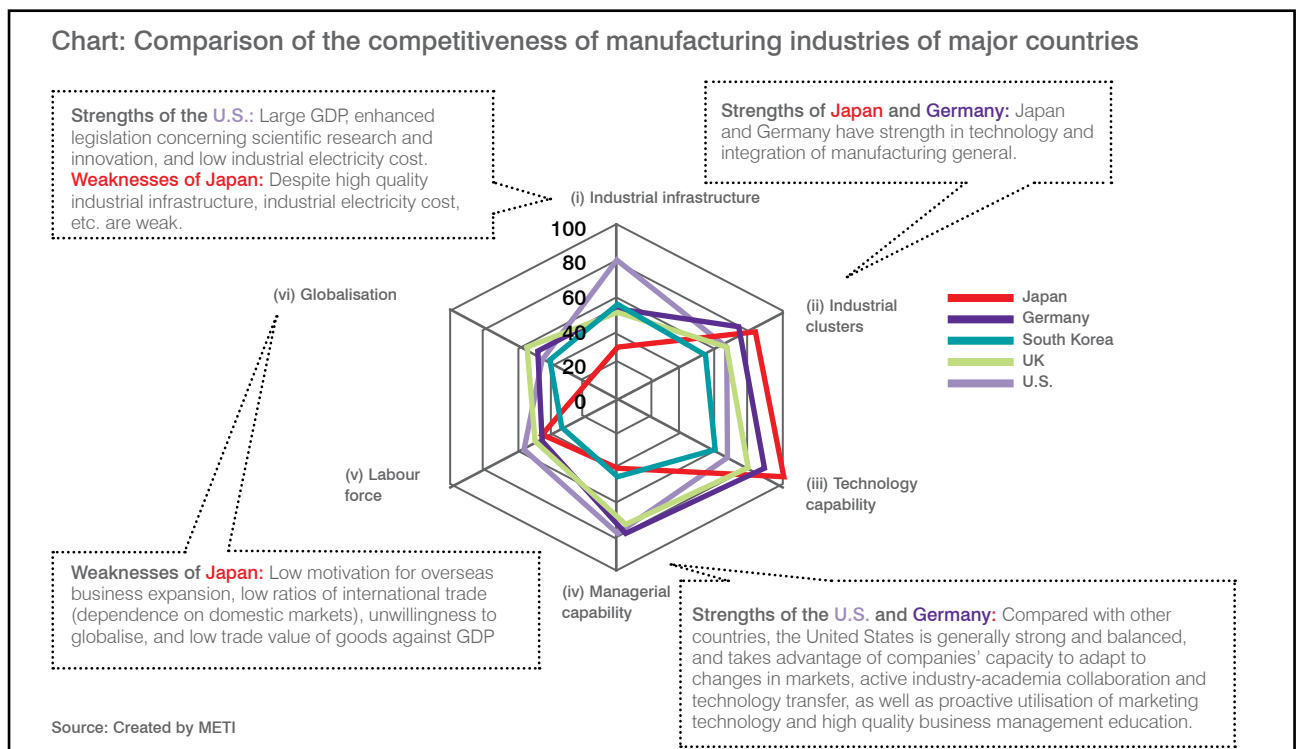
Figure 4: Importance of topics to the different technologies

⁴ www.cordis.europa.eu

In addition to adding functionality, the same drivers for sustainability and resource efficiency have been highlighted to focus efforts to improve the SEAC industry's potential to influence more products and create higher impact (see Fig 4). Fundamental understanding of SEAC processes and products is highlighted and the effective engagement of academic characterisation and demonstration centres with industry noted as a valuable resource to be made available along with production scale technology transfer capability⁵. The Fraunhofer system has been noted as the benchmark approach to achieving rapid demonstration of new technologies to provide confidence for industry to invest in change. Finally, REACH is noted, in common with all European countries, as a key challenge as well as an opportunity for the companies that can solve issues such as Cr(VI) replacements.

In **China** the SEAC community possesses numerous national and provincial associations and is clearly embedded in many different sectors in much the same way as it is in other countries including the UK. It is a growth area and government has set out a series of policies to provide direction and encourage technology development in the form of a roadmap issued by the Chinese Academy of Science.⁶ The 2020 goals align well with the SEAC SIG findings with protective coatings, replacement of toxic materials and development of new emerging deposition technologies highlighted. Again, cross-sector learning is noted as an enabler to increase industry's access to the science knowledge base.

In **Japan** manufacturing challenges in general rather than SEAC technologies specifically, were the focus of most of the accessible documents, as exemplified by the Japanese government ministry METI, which used a



⁵ U Konig, Central Association of Surface Treatment Professional (ZVO) Germany - Article in EURAIL, 21, 66-70

⁶ China Surface Engineering Summit 2012

⁷ Summary of the Whitepaper on Manufacturing Industries; FY2012 Monodzukuri, June 2012

spider diagram to demonstrate the comparative strengths and weaknesses in selected competing countries.⁷ Japan and Germany show strength in technology and integration of manufacturing in general, whilst the US, Germany and UK have good managerial capability. The US was highlighted as being strong in adapting to change in markets and having active industry-academia collaboration and technology transfer.

These findings are further confirmed in a World Economic Forum Report⁸ which suggests five policies that could advance manufacturing as recommended by executives questioned for the purpose of the report. One of these proposed policies is particularly pertinent to the SEAC SIG report in that it recommends the adoption of "a science, technology and innovation policy which promotes advanced manufacturing". This policy suggestion contains many of the themes identified by the SEAC SIG study:

"... a highly educated workforce with strong STEM and creativity skills combined with policies that consistently promote superior science and technology research and development through to commercialisation - including the development of advanced manufacturing processes - were essential to national competitiveness.

Policies that support long-term funding for research institutions and public-private research partnerships as well as promote the **strong connectivity between research institutions and manufacturing enterprises** were considered key ingredients to **the development of powerful 'manufacturing-innovation ecosystems'**, enhancing overall workforce productivity and competitiveness and driving prosperity for the citizens of a nation."

⁸ The Future of Manufacturing: Opportunities to drive economic growth, 2012



7. TIME FOR A STRATEGIC CHANGE

This SEAC SIG study has highlighted the many strengths of the UK in surface engineering and advanced coatings. As one of the national competencies in high value manufacturing, the SEAC community has created a major and expanding supplier industry worth an estimated £11bn. Their products are vitally important to all of the UK's manufacturing sectors and are able to change market dynamics, enabling disruptive technologies in a diverse range of products, such as gas turbine engines, drill bits, architectural glass and orthopaedic implants.

An active innovation culture has enabled the SEAC sector to be internationally competitive. The community has built strong and long-term contacts between the research base and industry that are particularly effective when supportive and strong end users create and drive the supply chain and R&D programmes. They recognise that SEAC technology is able to address many of the problems and development issues faced by industry.

The study has also highlighted that suppliers need to develop their capabilities further if they are to provide the required service and confidence to customers in high value manufacturing sectors. If SEAC technology is to be viewed as an integral part of a product's design rather than an 'add-on' option or an expedient solution to a design defect, the industry must develop processes, design methodologies, and supporting tools compatible with the approaches being used by major manufacturers (Figure 5).

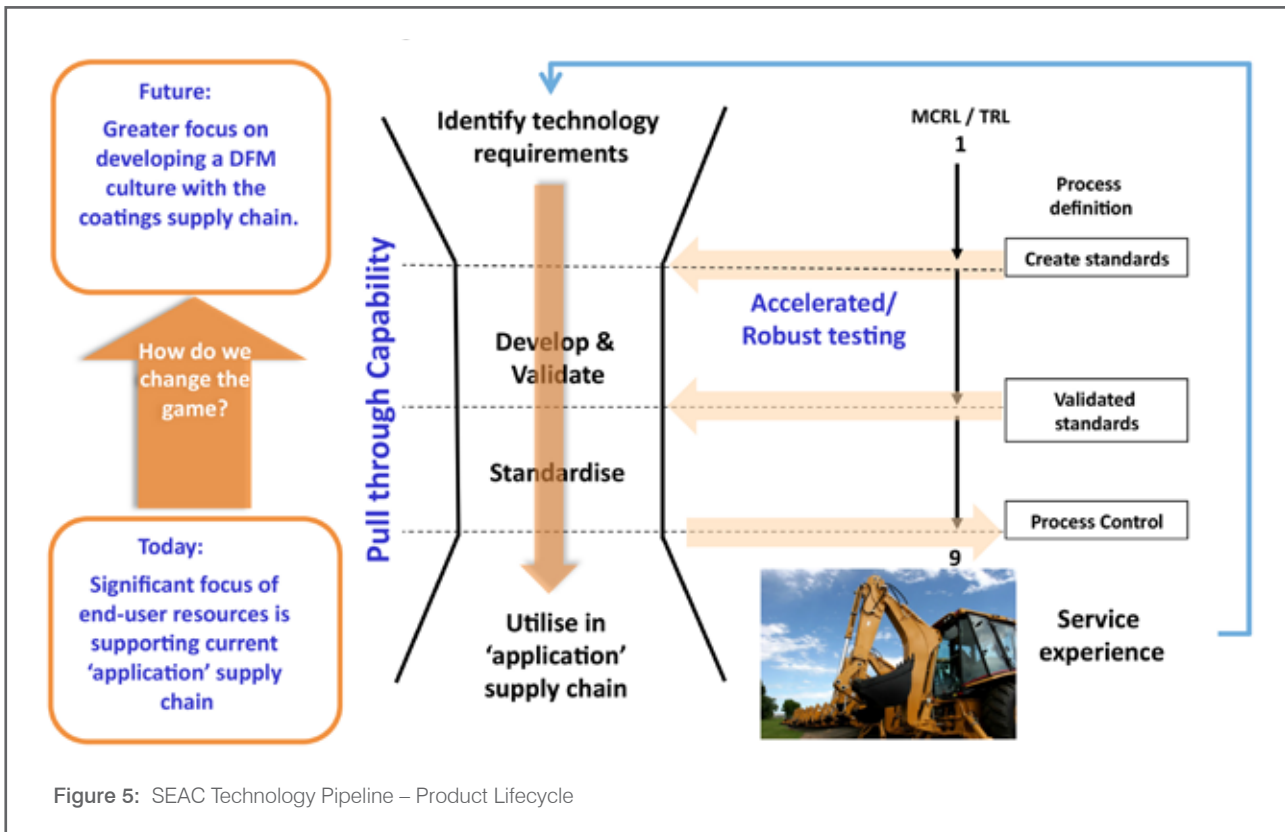


Figure 5: SEAC Technology Pipeline – Product Lifecycle

During the early stages of the product lifecycle, when products are developed from an idea through prototyping and into manufacturing, many participants are needed to provide information in the appropriate form and to have compatible manufacturing approaches. Increasingly companies are using 'design for manufacture' approaches to solve potential problems at the design phase and are adopting digital manufacturing approaches (see Figure 6).

If the UK SEAC sector is to remain competitive in the face of strong overseas competition it needs to radically enhance its approaches to both product design and manufacture.

Action is needed to further develop the 'manufacturing-innovation ecosystem' within the SEAC community to provide a more effective flow of technology and information between the companies and researchers within the sector and to enhance capabilities to meet these productivity and competitiveness challenges (Figure 7).

In areas facing similar issues such as metrology and advanced carbon-fibre composites, leadership groups, that bring all parts of the supply chain together, are currently proving effective in addressing cross-sectoral issues. The Product Verification Network is coordinating activities in measurement support, technology development, practical standards and guides and training. The Composite Leadership Forum is helping to provide strategic direction to the advanced composites industry and to identify key actions to enable the sector's ability to address commercial opportunities across many key sectors of the UK economy.

Discussions with companies from each part of the SEAC supply chain and industry representative bodies have shown support for establishing a surface engineering and advanced coatings network with a pre-competitive, common objective to establish a toolbox of 'design and verification and 'technical and commercial' capabilities.

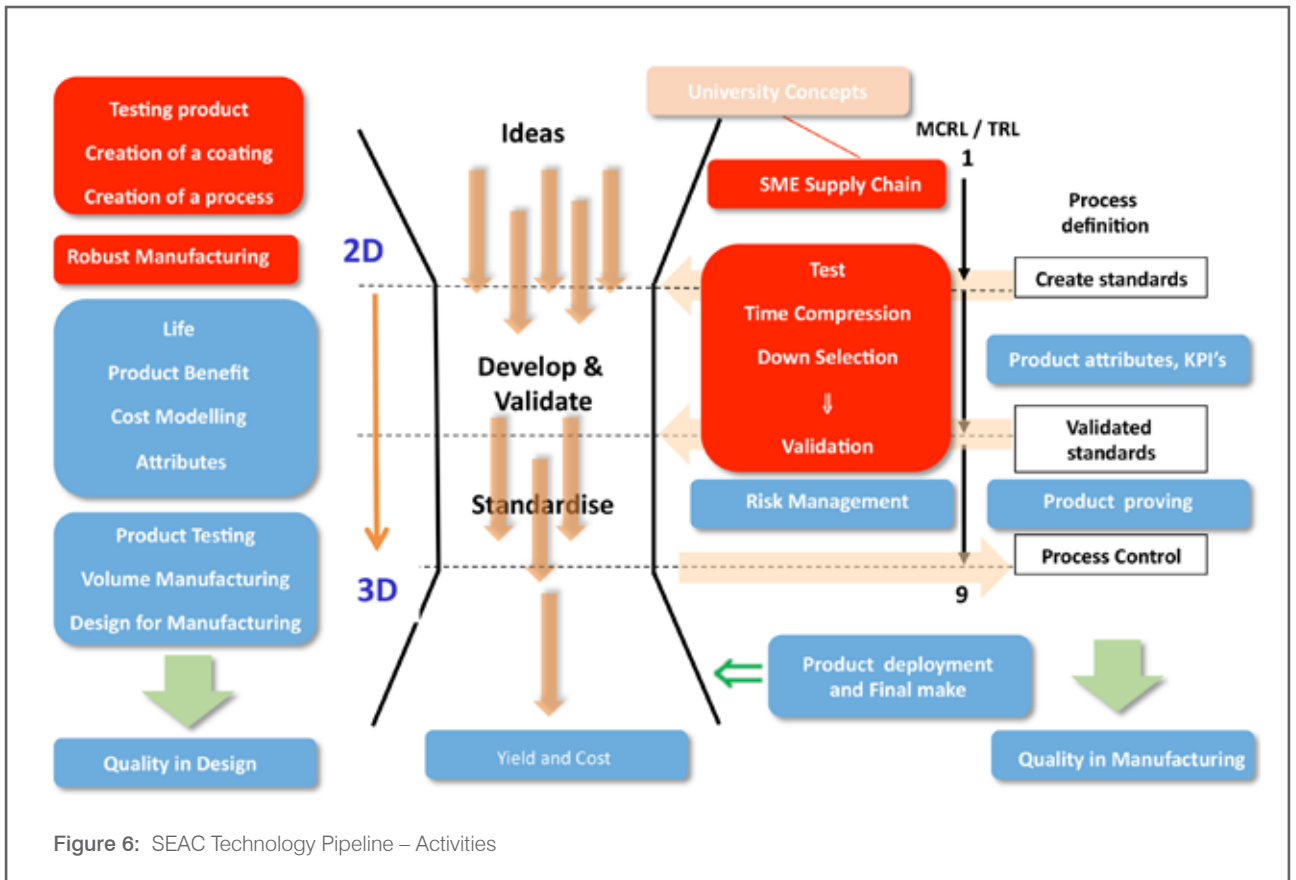
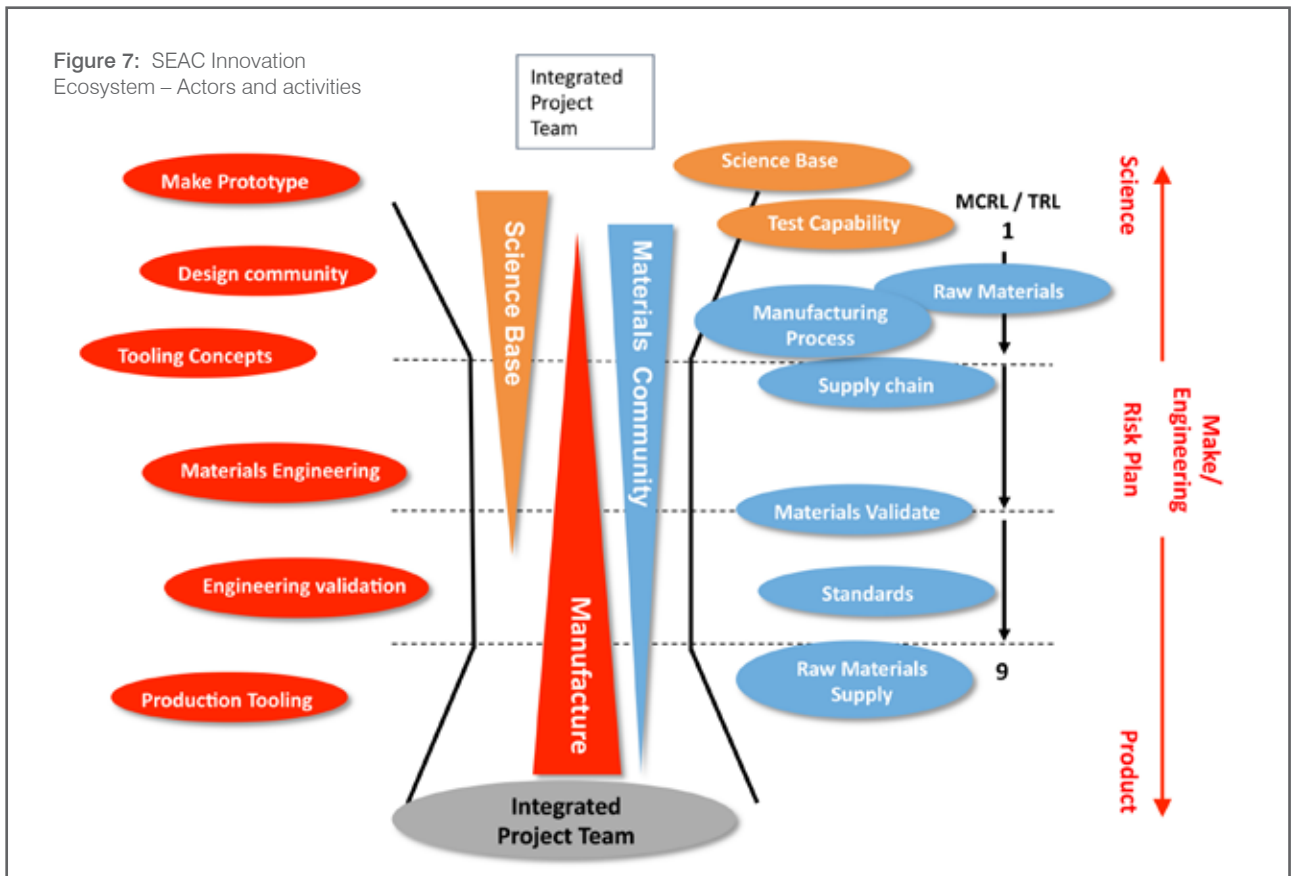


Figure 7: SEAC Innovation Ecosystem – Actors and activities



CASE STUDY F

ABRADABLE COATINGS

Abradable coating technology plays an important role in helping aero engines and industrial turbomachinery to achieve high efficiency by significantly reducing fuel consumption and emissions. Today's aero engines and industrial gas turbines need abradable coatings to enable them to meet their design requirements.

Clearance control coatings have been used since the late 1960s in turbomachinery, such as aero engines, industrial gas turbines and axial compressors to reduce the gas leakages around the tips of compressor and turbine blades and around the tips of labyrinth seal fins. These abradable coatings allow the rotating blade tips or labyrinth fins to machine their own seal path, thus minimising the gap between the rotating and stationary components and hence improving efficiency.

Thermal spray technology has been developed to provide a range of coating structures that are soft enough to allow the rotating component to machine the coating without suffering significant wear, but are hard enough to prevent erosion by the gas stream. Each of these structures is designed to operate over a specific temperature range between 300°C and 1200°C.

The use of abradable coatings can result in specific fuel consumption being reduced by up to 0.2% which translates into multi-million dollar savings in airline fuel bills. Gas compressor efficiencies can be improved by up to 2%.



8. CONCLUSIONS

The study has shown that the application of surface engineering and advanced coatings (SEAC) underpins most industrial and manufacturing sectors and is vital to the success of many commercial and industrial products and the creation of competitive advantage and income streams.

The established UK supply chain has a culture of innovation and effectively uses the existing support programmes to innovate its products and services. The research base has strong, long-term industrial contacts and international links. It works with industry through projects covering each innovation type (i.e. step change, evolutionary and enabling development) and Technology Readiness Levels 1 to 7. If funding agencies continue to provide opportunities in their support programmes to address development needs through surface engineering and advanced coatings, the expectation is that the supply chain will continue to propose development projects. There is also scope to develop, through collaborative research, further applications in areas such as construction, food and drink, and healthcare.

The application of emerging deposition technologies in new sectors requires specific attention such that demonstration of the 'fit for purpose' nature of disruptive approaches can be rapidly presented.

With a common theme of enhancing surface properties, the supply chain covers a diverse range of processes and services. The consequential fragmentation leads to poor flow of information and uncertainty for potential customers, which presents significant barriers to the wider adoption and application of SEAC technologies. Users of SEAC technology also have the perception that the supply chain is inward-looking and conservative rather than proactive to industry needs and yet to embrace the digital age.

If SEAC technology in the UK is to be viewed as a future HVM technology and thrive in increasingly competitive global markets, the sector must develop its capabilities to provide the service and confidence that customers are seeking. Moreover, the research base, supply chain and end users need to be better integrated to incorporate the principles of design for manufacture and design for process excellence.

Initiatives to raise the confidence and understanding of potential customers in SEAC technologies and the capability of the supply chain should address:

- Raising awareness, including accessing preproduction facilities and capabilities
- Increasing proactivity to address industry-wide issues
- The move to predictive design of coatings within systems
- An enabled consideration of surface engineering as a strategic manufacturing process.

The UK SEAC sector should also consider establishing a network that brings together all parts of the supply chain. This community of end users, academia and manufacturers should address pre-competitive, common objectives to establish a toolbox of 'design and verification' and 'technical and commercial' capabilities for SEAC. Basing the model on current successful technology networks will maximise the likelihood of success.

9. RECOMMENDATIONS

1. Establish a Leadership Forum for surface engineering and advanced coatings

The forum's objectives should include:

- Creating an organisational/activity model for the UK, similar to initiatives for metrology and composite materials, which promotes widening the application of SEAC technology drawn from the community of end users, academia and manufacturers.
- Developing a self-sustaining strategy to move from a disconnected tactical community to a strategic proactive grouping.
- Creation of a mechanism to promote activities such as:
 - Design and substitution for SEAC context
 - Targeting design authorities
 - Moving from reactive to proactive design of SEAC-based solutions
 - Substituting Legacy Surface Engineering with a 'plug and play' capability
 - Marriage between the science and 'art' of SEAC on one side and the exact world of specifications and application performance standards on the other side.
 - Creating a testing methodology to introduce SEAC into product lifecycle at managed levels of risk.
 - Introducing digital-based design and processing methods.

As surface engineering and advanced coatings encompasses many industries and techniques, focus on a particular surfacing technology would be too narrow and an approach is needed that involves the wide-ranging interests of stakeholders. Consequently any network structure should work with as many of the sector's stakeholder groups as possible to shape a competitive agenda for the UK (see Figure 8). To maximise the likelihood of success an impartial host respected by the SEAC community is needed to establish and manage the initiative.

Early-stage work should develop more detailed roadmaps highlighting specific activities and timescales, engage support agencies around the themes identified by this study, and test the feasibility of the approach in creating change for the sector - gauging if the community could draw together to create tangible and effective change in these areas.

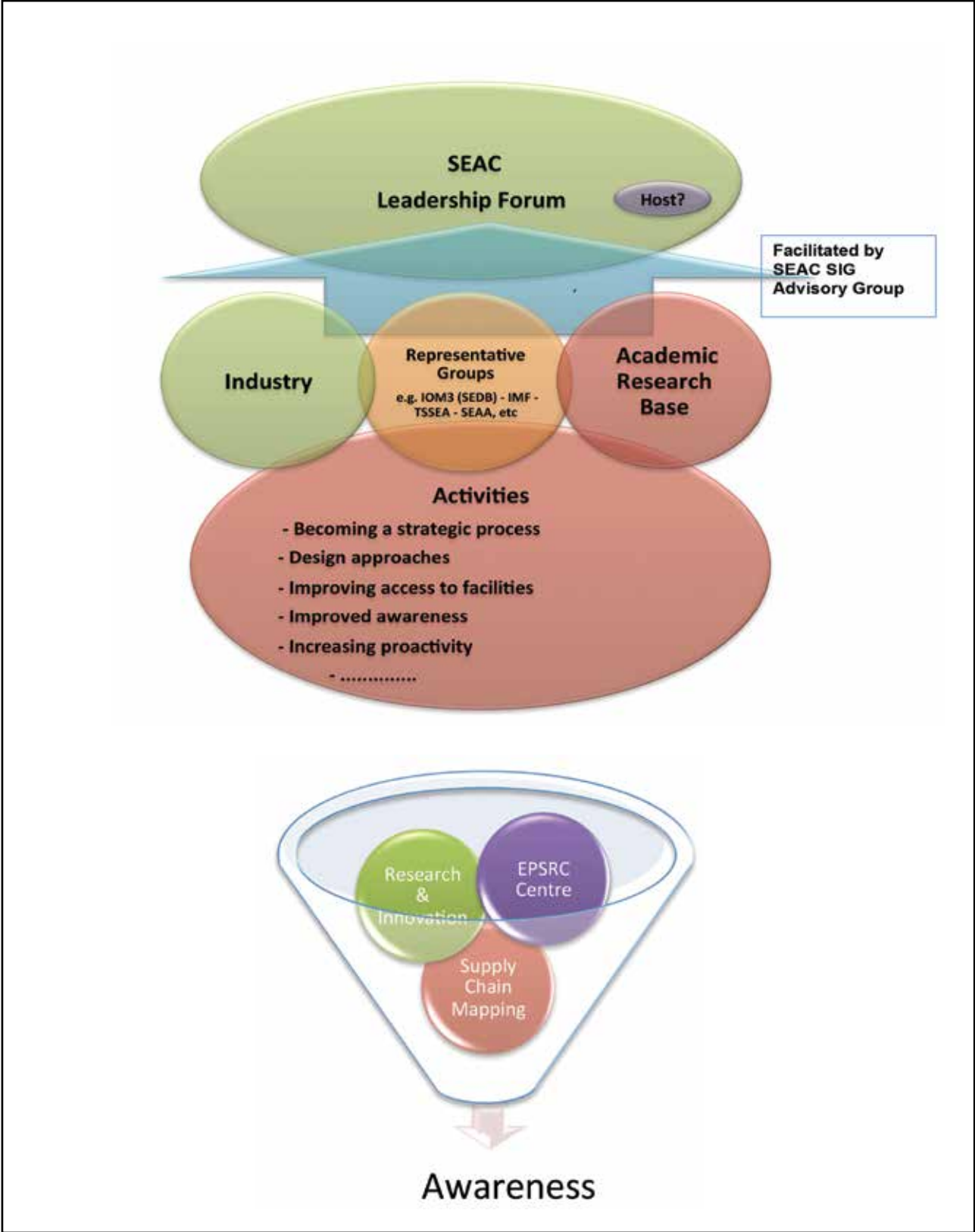


Figure 8: The themes identified by the stakeholder workshop form the basis of further recommendations and provide a good focus for the Leadership Forum's initial activities.

2. SEAC to become a strategic process aligned with high value manufacturing principles

- Initiatives to encourage
 - Process modelling, simulation and automation
 - Improved process control
 - Adaptive process control and inline monitoring, for example intelligent sampling and QA monitoring linked to real-time processing
 - Developing an understanding of what could be done with digital techniques and how this could be achieved
 - Workforce reskilling
 - Exploiting the UK lead in software through incorporation into automated SEAC technologies

3. SEAC supply chain to embrace design for manufacture

- End users need to realise the value of the coating at the design stage
- Engineering Centre for Doctoral Training in Surface Engineering would integrate all stages of SEAC technology from development through to design, application, manufacture and CIM focussing on the manufacturing process and capabilities.
- Need to acquire better performance characterisation to enable predictive design
 - Structure/property/performance data
 - Accelerated tests are needed
 - Life cycle simulation to predict in-service life
 - Reviewing existing data on the product life cycle bringing current tools to interpret and predict
- Need to find ways in which the testing data can be interpreted to enable design, manufacturing and application environments. Tools that link to the product lifecycle would allow companies to maintain their know-how yet make better use of data.

4. Easy access to facilities and means of building manufacturing capability and capacity

- Need to recognise the criticality of scaling processes and pre-production activities to de-risk investment and provide more accurate analysis of return on investment.
- Increased awareness and access to existing preproduction-level equipment and capabilities in companies and the research base will help to meet this objective.
- Establishing a virtual network of SEAC centres would assist in linking up the supply chain and ensure alignment with respective Catapult centres.
- Enhancing production facilities in terms of size and throughput in some technologies and applications will be needed.

5. Improve awareness of SEAC technologies and processes across all UK manufacturing sectors

- Linking the coating industry and researchers with end users and funding bodies through an independent third party such as the KTN
- Organising activities to build momentum and understanding such as events to promote knowledge transfer
- Encouraging cross-sector exploitation
- Increased awareness and access to existing production-level equipment and capabilities in companies and the research base
- Educating the supply chain on lifecycle cost analysis to justify new technology introduction and de-risk the process
- Developing design methodologies to exploit SEAC technologies to maximum benefit
- Creating a common language and understanding between SEAC providers and customers

6. Increase proactivity within the SEAC supply chain

- Adopting a proactive approach to issues faced by the SEAC community due to changes in legislation:
 - Stimulate UK-based solutions to environmental drivers – e.g. REACH, BPA (food and drink) – recognising that they can be both threats and opportunities
 - Anticipating future challenges raised by legislation
- Addressing the sustainability and environmental impact of coating systems
 - Sustainability of materials supply and choice
 - Developing recycling strategies and life cycle analysis approaches
 - Cross-sectoral approaches to responding to new regulation such as REACH, e.g. replacement of hexavalent chrome and cadmium-based coating systems
- Adopting a more pro-active role in international standardisation activities and establishing standards for processing and product validation
- Securing process know-how and trade secrets
- Investing in workforce skills through trade associations to support business growth and develop digital approaches within companies.

Funding Opportunities

The SEAC community sees funding as a necessary element to stimulate these actions. The question is: how can the support provide the maximum impact? A collaborative research and development call focussed on SEAC technology innovation will not be the most effective method for producing the changes needed. Analysis of the current collaborative projects indicates that the sector is taking advantage of current calls to innovate. Provided that SEAC technology is not put

outside the scope of future appropriate calls, it is likely that companies will continue to apply for support to innovate in this area. Additional effort to ensure coatings and surface engineering are included in calls to sectors not seen as traditional users of these technologies, e.g. the food and drink, healthcare and construction sectors, will broaden the reach and range of innovation.

CASE STUDY G

FUNCTIONAL COATINGS TO TURN BUILDINGS INTO POWER STATIONS

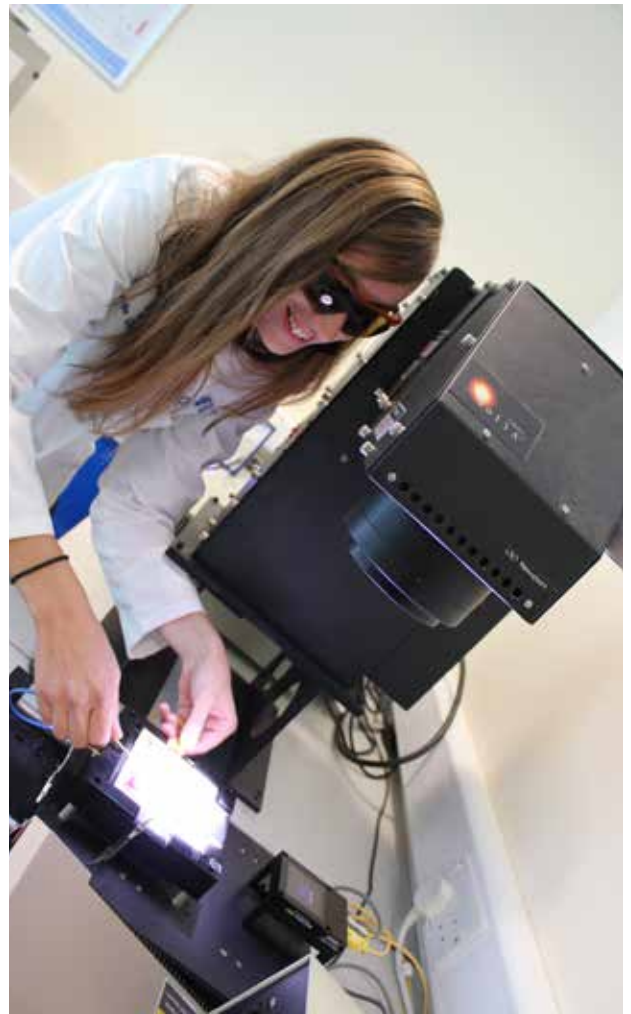
Based in Baglan Bay, South Wales, SPECIFIC is developing functional coatings that will transform the roofs and walls of buildings into surfaces that can generate, store and release solar energy.

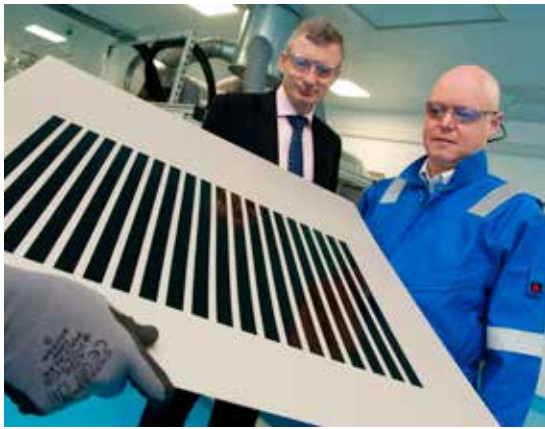
SPECIFIC is led by Swansea University in partnership with industrial partners including Tata Steel, BASF and NSG Pilkington and research partners including Imperial College London, Cardiff University, Bath University, Bangor University and Sheffield University. It is one of seven Innovation and Knowledge Centres set up to promote commercialisation of emerging technologies by creating early stage critical mass in an area of disruptive technology. The centre is funded by the Engineering and Physical Sciences Research Council (EPSRC), the Technology Strategy Board and the Welsh Government.

SPECIFIC's strategy is to make the building envelope active rather than passive (in both new and existing buildings) by enabling it to generate, store and release energy using a variety of functional coatings. It is particularly targeting realistic cost-effective solutions that can be mass-manufactured on a large scale using Earth-abundant, safe and environmentally sustainable materials. Technologies under development include a range of flexible photovoltaic devices, a solar air collector, a coating for large area heating, and a water treatment coating.

In addition to its development lines, SPECIFIC has pilot production lines that enable demonstration of full scale coating of up to 1.2m² sheet steel, glass and polymer substrate based products as well as a coil line for continuous processing of flexible (steel and polymer) materials up to 300mm in width.

The goal is to create a new £1bn high-value manufacturing industry with up to 10,000 new supply chain jobs, and to generate 10GW peak per annum by the 2020s (equivalent to five coal-fired power stations) thus reducing CO₂ emissions by 6 million tonnes per year.





In the short to medium term wider networking and feasibility studies in advance of a larger initiative are likely to have a greater impact on the sector than a focused CR&D call. If it is to be viewed as internationally competitive the SEAC sector needs to develop its capabilities to meet the requirements of companies whose business models are dependent on digitally enabled processes for manufacturing high value products. To thrive in this environment the sector needs to consider its approach to a range of specific issues, including product and process development, design for manufacture, standards, training and skills development.

APPENDIX A: SECTOR OPPORTUNITIES

A1.1 OPPORTUNITIES IN THE POWER GENERATION SECTOR

The global power generation sector is facing a period of unprecedented investment and development over the next two decades because:

- Global growth in demand for electrical power is predicted to virtually double over the period
- There will be enforced retirement of a substantial proportion of the current fleet of generation plants, e.g. plants in Europe opted out of the EU Large Combustion Plant Directive

The key drivers, both for new plant installations and for the enhancement of existing installations, will be:

- The need to maintain a reliable supply of electricity.
- The need to maintain security of supply of the fuels required for many power generation technologies
- The requirement to reduce the levels of emissions of CO₂ and other greenhouse gases

These issues will drive needs for enhancement of performance in power generation installations of all types and, in many cases, surface engineering may offer the optimum solutions.

The implications for each type of installation in the future 'power mix' can be summarised as below.

Fossil-fuel combustion generation

- The need to protect the surfaces of boiler pipes and tubes against increasingly aggressive fireside corrosion (arising from biomass firing/co-firing and oxy-fuel CCS) and steamside oxidation (arising from the adoption of ultra super critical steam conditions)
- The need to protect steam turbine components against more aggressive steam droplet erosion, particle erosion and steam oxidation attack
- The need to protect gas turbine components from more aggressive conditions, arising from increased operating temperatures and the use of 'dirtier' syngas fuels
- The need for enhanced sealing in gas and steam turbines

Nuclear power

Over the two-decade time period, no deployment of nuclear fusion is envisaged and the next generation of new nuclear fission build will not seek to enhance operating efficiencies from the current norms but will focus on enhanced safety features. This drive for enhanced safety, coupled with the need for extended operating lifetimes for both new build and existing installations, will lead to surface engineering opportunities in:

- The full fuel cycle – mining/extraction of the primary ores, fuel enrichment, fuel processing, fuel re-processing
- Nuclear fission hardware
- Nuclear plant de-commissioning
- Nuclear waste management

Renewables

- **Hydro-power:** this will be the dominant renewable technology globally. Repair and refurbishment of hydro-turbine components will be required to combat degradation by cavitation, pitting or particle erosion.
- **Wind Power:** turbine blades need to be protected against solid particle and foreign object damage. Blades and bearings also need to be protected against tribocorrosion. Corrosion protection will be required for high performance Nd-Fe-B permanent magnets used in marine environments in synchronous wind turbine drives without gear-boxes. There is a need for surface engineering solutions to combat tribological problems in gearboxes and in yaw and pitch drives. Turbine towers will also require protection against corrosion, biofouling and corrosion fatigue in marine environments.
- **Wave and Tidal technologies:** those involving the building of barrages or containments are close derivatives of hydro-power with similar material challenges; others are more aligned to wind turbines and are subject to similar challenges.
- **Solar Power:** although solar power is projected to contribute only a small percentage to the UK energy mix, there is a viable UK supply chain in this sector capable of delivering globally. Opportunities for surface engineering are likely to be in improved efficiency, cost reduction and large area application.

A1.2 OPPORTUNITIES IN THE AEROSPACE SECTOR

The growth of air traffic over the past 50 years has been dramatic and forecasts indicate that it will continue at 4-5% per annum. Despite periodic fluctuations in the global economy, the underlying upward trend will continue as flying becomes more affordable to an increasing number of people. The real growth is predicted to be in the emerging economies such as China, India, Latin America and Eastern Europe. Aviation currently accounts for 2% of global carbon dioxide emissions and could grow to about 5% in the next 30 years unless unchecked.

Aerospace technology programmes are targeted at minimising the environmental impact of aviation and ensuring the sustainable growth of the sector. For example, fuel burn can be reduced through propulsion developments, more efficient use of power for aircraft systems, lighter-weight materials and airframe drag reduction. Programmes to deliver these are key components of the National Aerospace Technology Strategy (NATS) and exploit UK strengths in academia, engineering innovation and advanced manufacturing.

Surface engineering plays an important part in the aerospace sector, not only in reducing its environmental impact but also in achieving the necessary safety and affordability (through life cost including initial costs, maintenance, fuel burn, repair, etc.) and reliability. It represents a performance enabler for the aerospace industry and a priority theme to maintain the UK manufacturing's position in the high-value-adding end of the manufacturing chain and in the provision of maintenance, repair and overhaul services.

Examples of challenges and opportunities in surface engineering within the aerospace sector are as follows:

- Protective coatings are becoming of critical importance to enable the operation of materials and components to operate in more stringent conditions. Substrates, coatings and the method of application need to be developed as a system and therefore optimised as such.
- The performance of coatings is becoming integral to the life of the component, therefore the prediction of the behaviour of coatings and surface treatments

as well as the estimate of any rates of degradation are important.

- Increased cleanliness will be a requirement as materials are pushed into ever more extreme operating environments and complex manufacturing processes.
- The development of anti-fretage and anti-erosion coatings for aeroengines has been identified under the theme of reliability.
- Polymer composites are increasingly used in engine structures and new coatings are required to improve their surface properties. Increased use of composites in airframes will require improved coating with enhanced abilities for damage detection and repair.
- Continual development of metallic and fabrication techniques, particularly to deliver net shape products will require improvements in surface engineering and coating techniques.
- Development of improved damage tolerant and corrosion protected surfaces.

The impact of environmental legislation limiting or completely restricting the use of certain materials such as cadmium and chromium-based surface protection schemes in manufacture is being felt and such restrictions will have implications for repairs and modifications to existing aircraft. REACH has a number of challenges for the aerospace industry – some in common with other industries to a degree, however:

- Aerospace has a huge legacy product range to deal with and so any changes are not allowed to invalidate certified products
- Existing 'traditional' processes that are to be replaced have years of performance data and therefore there is limited opportunity to use new technology to backfill on mature products
- Testing of new processes is short term, which might not be a true representation of service
- A key challenge for aerospace will be how any new processes can be stated as meeting the performance of the traditional process with 30-40 year or 60,000 landing life required

A1.3 OPPORTUNITIES IN THE HEALTHCARE SECTOR

In recent years the healthcare landscape has been influenced by rapid demographic changes such as increasing average age and obesity and the emergence of 'new' technologies such as tissue engineering.

A major driver in healthcare is to slow the rate of increase in healthcare spend. For example, the USA spent \$2.3 trillion in 2008, which is unsustainable.

Budgetary pressures and the changes in healthcare needs create significant opportunities for companies that are developing products that reduce hospital stays (e.g. with longer lasting implants) and address the major diseases that Western hospitals are trying to treat.

In general, materials used in healthcare applications do not operate at optimum functionality and thus there are significant opportunities for improvement as well as the development of new applications.

Not only do biomaterials need to exhibit ranges of mechanical and chemical properties during use, as is a prerequisite for applications for all engineering materials, but they also have to display biocompatibility, bio-inertness or bioactivity depending on specific applications.

In response to these changes, it is imperative that materials science and technology keep pace. Within this field surface engineering has a major role to play because of its flexibility in addressing particular applications and requirements; for example, its ability to adopt nanotechnology to create functional structures at the cellular scale and its cost effectiveness compared to the use of monolithic materials.

Examples of where advances in surface engineering technology hold out the prospect of significant advances in products that have the potential to find applications in the global healthcare marketplace are:

Implants & Devices

- Anti-infection surfaces for implants and catheters
- Implant surfaces for particle release minimisation
- Implant surfaces with enhanced bio-adhesion properties
- Development of smart, biomimetic surfaces
- Smart implants (surface-mounted sensors) with self-monitoring functionality
- Technologies for producing customised implants
- Coated powders as precursors for high value device manufacturing
- Cardiovascular devices such as stents or valves
- Intelligent drug delivery surfaces

General

- Anti-microbial treatments for handleable surfaces
- Functional coatings for medical textiles and dressings (e.g. anti-microbial)
- Systems for modelling, testing and simulating surface performance
- Computer modelling of surface / cell interactions
- Scaffolds for tissue engineering applications

A1.4 OPPORTUNITIES IN THE LAND AND MARINE TRANSPORT SECTORS

Recently developed industry technology roadmaps for automotive, rail and marine sectors identified key common challenge areas, which include energy efficiency and lightweight materials.

Although surface engineering is not explicitly cited, it is of critical importance to developing technologies to meet these challenges.

The development of new engineered surfaces is just one aspect of the challenge. The demonstration and incorporation of new techniques and capabilities into design, manufacture and operational requirements are of equal importance. The automotive, rail and marine sectors are mature and risk-averse, and the introduction of new technologies and techniques often requires

significant testing and demonstration before adoption. Crossing this 'valley of death' in this sector is often a challenge for the currently fragmented and disparate surface engineering community.

Below are a number of challenges identified by industry that require surface engineered solutions and give a flavour of the very varied and broad impact that surface engineering has on this substantial market.

- Energy storage and management: the development of new alternative power sources such as electricity and hydrogen require the development of new storage and management systems using novel materials and techniques.
- Engine efficiency: the constant drive to use as little energy as possible and meet ever stricter emissions regulations requires engines that incorporate further refinement and improvement of the use of low-friction coatings and materials.
- Lightweight vehicles and powertrains will push the use of new multi materials bonded and coated in new ways to deliver both structural gains as well as material protection.
- Low-friction coatings in marine applications will be required to limit damage to the environment, reduce VOC emissions and reduce the transfer of species across waterways. In a recent study sponsored by Marintek, average vessel speed loss is calculated at 5% for the 60 months lifetime of an antifouling paint. If converted to the extra fuel needed to maintain speed, vessels require about a 15% increase in fuel consumption for the given 60-month period.

A1.5 CROSS SECTOR OPPORTUNITIES

Innovation developed in the surface engineering supply chain can be applicable to many different applications and can readily be transferred to different sectors, e.g. surface engineering solutions such as hard chrome alternatives developed in the aerospace industry can be applicable to the automotive and other sectors such as oil and gas.

Technical challenges that will drive the growth of the market for surface engineering across many application sectors include:

- Conservation of scarce materials
- The use of lighter, low-cost and sustainable substrates
- The increasing need to combat wear and corrosion in increasingly aggressive environments
- Reduction of environmental impact through more sustainable materials and processes

