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David Kennedy
Technological University Dublin, david.kennedy@tudublin.ie

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Exploitation of Surface Engineering Technology Research

David M. Kennedy
Department of Mechanical Engineering,
Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland

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Abstract

Surface engineering refers to a wide range of technologies that design and modify the surface properties and characteristics of components. The applications are very broad from macro to nano and from extremely hard materials to polymeric coatings. The uses are found in many engineering, energy, gas and oil, transport, medical, cosmetic, optical, chemical and sports industries. Research in this technology is ongoing and the benefits that can be derived are enormous. The design, wear and tribological properties of components for instance have been greatly enhanced by surface engineering and the economic benefits to industries far outweigh the cost and use of traditional materials. Surface coatings and surface modification as illustrated in Figure 1. represent two key methods of surface deposition. This paper discusses describes the application of this technology and the potential benefits to be derived from current research and innovation in this discipline.

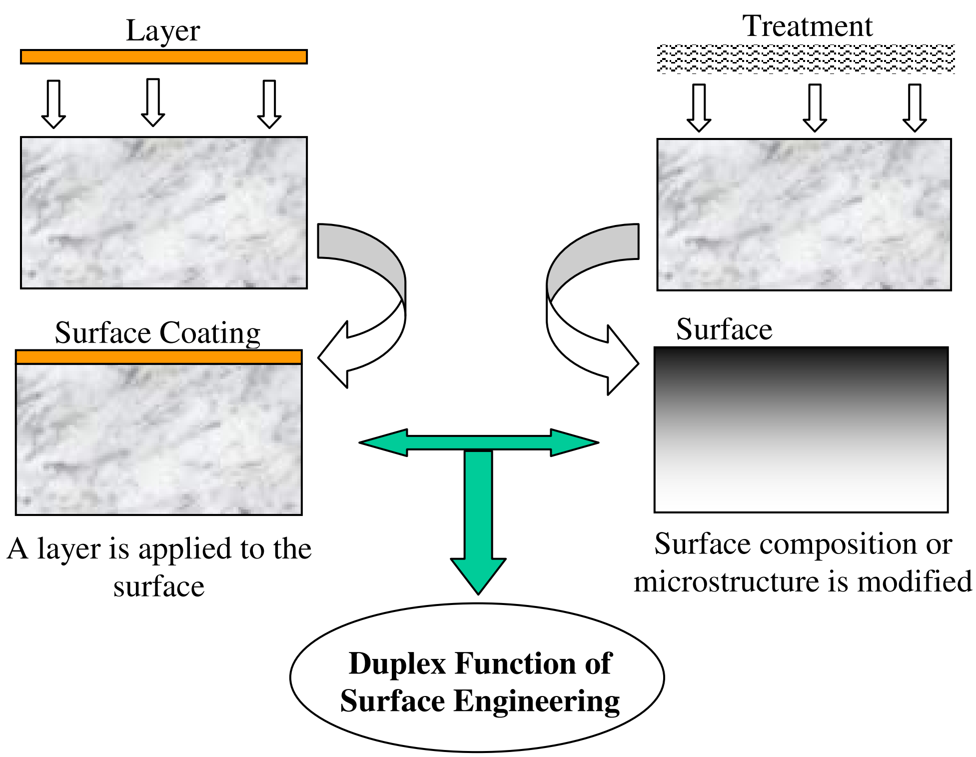

Figure 1. Surface Engineering Methods

1.0 Introduction

Considerable progress has been made over the last few decades in the development, testing and characteristics of advanced Surface Engineering. Prior to these developments, materials were subjected to heat treatments, paint, galvanising, alloying, anodising, carburising, and shot blasting which had limited effects on material properties and component enhancement. Countries such as Germany, Britain, France, United States of America, Australia, India and China have developed and exploited the uses of surface coatings for Industrial applications in many disciplines of Science and Engineering. A current report in Britain produced by the National Surface Engineering Centre (Nasurf) estimates that Surface Engineering processes could affect manufactured products worth £120 Billion and Surface Engineering is currently worth over £20 Billion to the U.K. economy. It has been estimated that the cost of wear, fatigue and corrosion amount to 4 % of GDP, the value of the UK coating market in 2005 to be in the region of UK£21.3bn and the value of products critically affected by coatings for the UK is in the order of £143bn [1]. Surface Engineering is continually evolving, where researchers are exploiting new discoveries and applications for coatings, both from nature, replacing old methods and from experimentation. Common industries and sectors where surface engineering is applied include:

Aerospace
Medical
Electronics
Construction
Mining
Machine Tools
Aerospace
Food and Packaging
Power generation
Renewable Energy
Micro and nanotechnology
Mechanical and Manufacturing
Chemical
Electronics
Offshore operations
Sport
Transport
Agriculture
Built environment
Solar & Hydrogen

In practice, coatings are used to improve the following surface properties:

(i) Corrosion protection.
(ii) Decorative purposes.
(iii) Hardness.
(vi) Electrical conductivity.
(v) Solderability.
(vi) Build up of material for restoration.
(vii) Wear resistance.
(viii) Optical or thermal reflectivity.
(ix) Oil retention.
(x) Thermal conductivity.

Some requirements of coatings at high temperatures may include:

(i) High melting temperature to protect the substrates.
(ii) Hardness.
(iii) Corrosion resistance.
(iv) Adhesive strength
(v) Low diffusion to prevent internal substrate corrosion.
(vi) High density, to avoid gas flux through pores to the substrate.
(vii) Stress free or in a state of compressive stress at working temperature.

The lists are extensive but not exhaustive as Surface Engineering has an impact on most standard and innovative products used today. The applications of surface coatings have been extensively explored and it is one of the fields of engineering and science that continues to offer innovative solutions to advanced technologies. Such applications include coatings in the sports industry, biomedical/orthopaedics, dentistry, cancer therapy, and the art industry.

2.0 Current and future applications

In the cutting tool industry, modern cutting applications cannot be accomplished without protecting the tools with a thin wear-resistant, diffusion barrier coating. These applications include high speed cutting, hard machining of high hardness (Rockwell>60C) materials, dry cutting and cutting of materials such as Titanium, AlSi alloys or other non-ferrous materials. They enhance wear resistance and hardness at the cutting edge and reduce diffusion and friction. Other applications include high toughness as in punching and piercing operations. Examples of TiN coated machining tools are shown in Figure 2. In the transport industry, approximately 6% of the costs of manufacturing engines and transmissions involve coating technologies [2]. Surface coatings in the transport industry can be broken into power units, vehicle components and fixed permanent structures. Other more advanced applications include Tribochemistry, Transmission Systems and Engine Systems [3]. Coatings used in power generation units such as diesel engines and power transmission are well advanced today. They protect the power units from erosion and wear. Suspension and brakes are coated with thermally sprayed coatings to improve wear resistance, extending service life. Polymer coatings are applied to exposed areas of vehicles and they act as a body coat on some vehicles to improve aesthetics, abrasion and corrosion resistance. Polymer coatings provide low noise solutions. Marine applications include bridges and oil rigs to combat saltwater corrosion and sand abrasion problems.

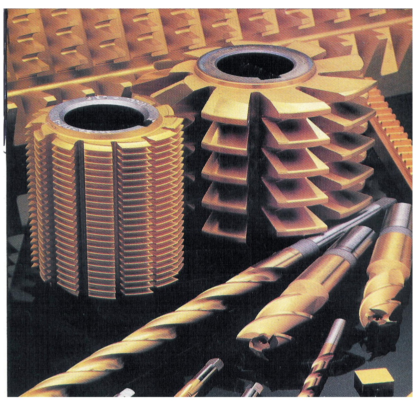

Figure 2. TiN Coated tools

In the aerospace industry, coatings on engine parts have been practised for over 50 years. Surface coated gas turbine engine provide high strength at high temperatures, corrosion resistance, abradable seals and bearing properties. Spacecraft components such as gears and ball bearings, coated with MoS_2, applied by PVD magnetron sputtering helps lower the heat generated within the transmission system. Surface modifications improve the performance of many components. Some of the future applications that will require research and development include engine and transmission design, especially for engines using hydrogen storage tanks and fuels.

2.1 Sports Industry Applications

Surface engineering of titanium oxide for motor sports has proved to be an effective method of optimising engine parts and enhancing racing car performance. A reduction of inertial mass should lead to increased speed, greater acceleration and better fuel efficiency and higher performance. Titanium alloys have an excellent combination of properties in terms of high strength/weight ratio, resistance to corrosion and bio-compatibility. As described by Bell and Dong [4], surface engineered titanium will be the material of the 21st century. Engines should have low friction and low wear contacts at high temperatures in chemically reactive environments. Cam followers coated with DLC possess very low friction coefficient, reducing sliding friction by up to 80%. Applying surface coatings to golf clubs is a novel approach to improving contact and/or frictional effects, resulting in friction control of golf clubs, thus effecting ball spin. This will help determine the distance, spin and direction of flow of the ball. Typical surface modifications to golf clubs include TiN and Carbide coatings, shot peening and surface shape design. Other applications in the sport industry include snow ski designs, curling, cycling, soccer boots and protective clothing. Reducing or increasing friction in the competitive sports can be the difference between winning and losing. Table 1. shows a list of the current and future potential for surface engineering materials, processes and applications.

Material	**Function or role**	**R& D**	**Process**	**Coating type**	**Applications**
Metals	Corrosion	Quality	Thermal	Nano	Textiles
Ceramics	Wear	Design	PVD/CVD	Micro	Sport
Polymers	Friction	Testing	Sputtering	Thin	Marine and offshore
Powder form	Tribo corrosion	Innovation	Plasma	Thick	Machinery
Rod form	Adhesion	Colour and texture	Dipping	Multi layer	Building Industry
Atomic form	Oxidation	Thermoche-mical	Mechanical	Multi process	Renewable energy (PV)
Gaseous form	Fracture	Electrochemical	Heat Treatment	Hard	Transport
Liquid form	Optical	Paints & Organic coatings	Ion Implantation	Soft	Aerospace
Plasma	Fatigue	Characterisatio n	Laser & Electron Beam	Transparen t	Tools
	Thermal barrier	Surface modelling	Electrochemical	Insulator	Biomedical
	Diffusion barrier	Mechanics	Atmospheric & Vacuum	Conductor	Cutlery & kitchenware
		Cost reduction		Tough	Electronic
		Optical	Anodising	Hard	Mining
		Bio medical		Abradable	Military
		Sports & motor racing		Weight reduction	Porosity

Table 1. Surface Engineering diversity

3.1 Research and development

Surface engineering offers materials savings and environmental benefits in numerous applications, e.g. through increased service life, reduced emissions, reduced energy consumption, and improved recyclability. Many modern surface engineering processes have low environmental impact as opposed to old heat treatment and chemical treatment processes. Coatings for wind, wave, solar and PV systems will be required to enhance their environmental uses and make them more efficient.

Reduction in weight, particularly for motor vehicles by using aluminium, magnesium and titanium alloys require surface engineering to improve corrosion and tribological properties. Deposition of titanium alloys has increased wear resistance substantially, permitting their use for lightweight components in Formula One vehicles and in other advanced applications in the offshore, biomedical, and sports sectors.

Figure 3. Polymer spraying

Polymer coatings for structural applications give strong potential for growth as well as being a cost effective and rapid method of depositing coatings on a wide range of materials without affecting their mechanical or physical properties. This is a fast and flexible deposition process as shown in Figure 3. Applications of functionally graded structures capable of a response to their environment will increase. This will involve further growth in the use of sensor technology, increasingly combined with applications such as smart oxidation resistant layers for gas turbines, and food packaging. Some 80% of aircraft vehicles and components are dependent on surface engineered components. Examples include coatings for gas turbines for power generation. Packaging such as beverage cans rely on coated tools and dies. Coatings have improved the quality of packaging through water and gas barriers on food products. Punch tools using, TiN, DLC or CBN have extended their use and life.

From 2005 some 50% of all architectural glass will be coated with materials to reduce glare, heat loss and improve aesthetics. Glass products can be coated to prevent breakage by using tin oxide films. Further development of such coatings, will reduce glass weight and deliver thinner thicknesses. Currently surface engineering makes a significant impact on architectural and automotive glass, display panels, mirrors and spectacles. Developments in coating technology now permit multi-layer structures with specific properties to be deposited on glass. Applications include;

- low-emissivity (Low-E) and solar control coatings on architectural glass;
- solar control and electrically conductive coatings on automotive glass;
- high reflectance coatings for solar collectors and telescope mirrors;
- moderate reflectance coatings for headlamp reflectors and rear view mirrors;
- photovoltaic coatings for solar cells; anti-scratch coatings on opthalmic lenses;
- conductive anti-reflective coatings for computer monitors and television screens.
- scratch-resistance and corrosion resistance.

The films are typically less that 1 μm thick and deposited using PVD and CVD.

Biomedical devices, from prosthetic joints to substrates for tissue regeneration to advanced biosensors rely on engineered surfaces to provide both functionality and biocompatibility. Surgical implants can be coated with porous titanium or with synthetic bone to promote fixation in the body as shown in Figure 4.

Figure 4. Coated implants

Almost 100% of electronic components and advanced sensors, optical coatings, etc. are fabricated using surface engineering technologies.

3.2Thermally sprayed coatings

Thermal spraying is now regarded as one of the key enabling surface engineering technologies. Applications include automobiles, aerospace, medical, marine and sports etc. Material that have a well defined melting point and does not decompose when heated can be thermally sprayed and over 500 materials are now available for coating selection. Aerospace engineers apply these coatings at the manufacturing stage and during repair. Thermal barrier coatings are used to protect against extreme heat. Abradable coatings allow the rotating blade tip to machine its own seal. In vehicle design, cast iron liners have been replaced with a thin plasma coating and lightweight brake discs can be coated with a ceramic. Rolls used in the paper, printing and steel industries are protected against wear and corrosion. Water and chemical pump impellors and housings are now coated to prevent corrosion and wear.

4.0 Coating Techniques and Processes

Figure 5. shows the fusing of a WC-Co coating to an aluminium substrate providing a hard wear resistant coating to a lightweight material. Figure 6. shows the main components of the thermal spray gun. Some examples of coating process and their associated costs and functions are highlighted in Table 2 while Table 3. shows an outline of traditional and advanced surface coating processes and their applications.

Figure 5. WC-Co coating process

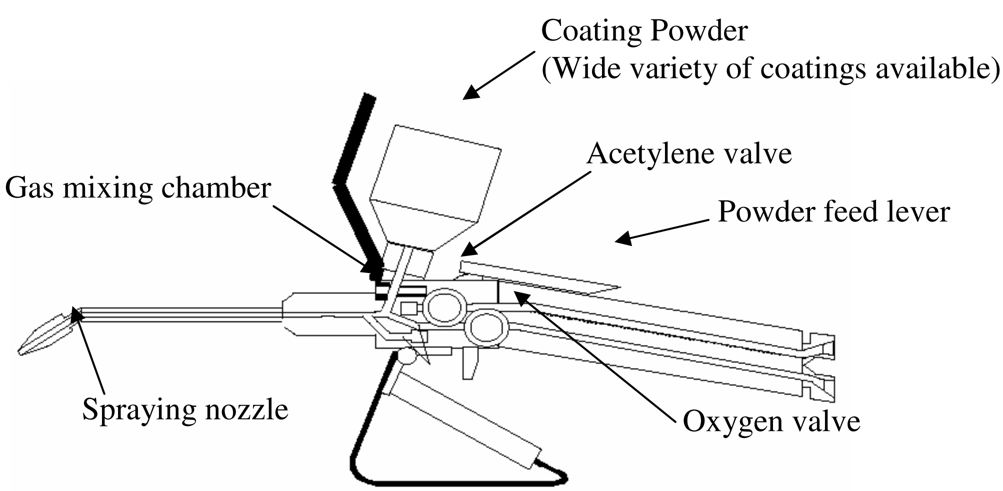

Figure 6. Thermal Spray Torch

PROCESSES	TYPES	PROPERTIES	APPLICATIONS
Chemical Vapour	Diamond film	Hardness	Cutting tools and Dies
Deposition (CVD)		Wear resistance	Drills, Mills, Punches
Physical Vapour	Diamond like	Shock resistance	Tapping, Reaming
Deposition (PVD)	Carbon (DLC)	Chemical resistance	Extruders
Ion- plating	Titanium Nitride	High Temperature	Injection moulding
		Resistance	Ball Bearings
Ion implantation	Titanium Carbide	Low friction	Rolling mills
Weld facing	Silicon Nitride	Toughness	Mining equipment
Cladding			
			Broaching
Thermal spray	WC-Co		Forging, Quarrying
	Tungsten carbide		
Plasma spray	Aluminium oxide	Diffusion barrier	
	Silicone carbide	Impact resistance	Pump housings
	Chromium carbide	Fatigue resistance	Aircraft components
Laser surfacing	Chromium oxide	Corrosion resistance	Agricultural parts
Dipping		Surface finish	Electrical contactors
Electroplating		Electrical insulation	Engine parts

Table 2. Traditional and advanced applications of surface Engineering

Process	**Costs**	**Value**	**Applications**	**Functions**	**User friendly**	**Flexibility**
Plasma spraying	Expensive to setup and train staff in. High power requirement Water/Air cooling, high material consumption.	Used for high value parts such as aeronautical engines and exhaust parts, wide range of coatings and thicknesses. High/rapid deposition rates.	Wide range of thick coatings. Athmospheric Small and large components. Broad range of substrates	Wear, salvage, Corrosion Erosion, , Abrasion, Hardness, Friction coatings, thermal barriers etc	Safety precaution such as extreme noise. Mobile, High temperatures. Post treatment allowed	Very versatile, Mobile, Rapid pre treatment and post treatment, Thick and thin coatings, line of site.
Electroplating	Relatively cheap to set up but environmentally unpopular, requires skilled staff.	Broad range of coatings, low waste Can be used for metallic and non metallic surfaces. Broad range of materials can be deposited.	Decorative, wear and wide range of coatings, thick and thin, Need conductive substrates.	Decorative, wear, conductive coatings,	Need different baths and electrodes for different metals, precision control for good deposit rates and coating quality.	Limited in coating hardness, Sample sizes, non mobile, non line of site process. Limited to certain substrates, no heat treatment of substrates
CVD & PVD	Expensive to set up but relatively clean, fully automatic, requires skilled operators, expensive and	Excellent life of components, used for high value but relatively small	Cutting tips and tools, implants, engine parts, high hardness, wear, impact resistant coatings	Thin coatings, high bond strength, low porosity coatings,	Fully automatic, Slow growth rate, non mobile, relatively small sample	Restricted to small components, requires expert operators, wide range of coatings and

	slow pre cleaning	components, not suitable for salvage,			size, PVD: line of site	multi-layers, not good for resalvage work.
Sheradising	Relatively cheap process but limited mainly to steels.	High corrosion resistant process where zinc is used on threads of nuts and bolts,	Steel components suchas metal casings, nuts and bolts where clogging of threads does not occur.	Thin uniform coating of zinc applied at approximat ely 370oC in rotating drum.	Simple process to develop and control. Limited to only a few applications	Relatively fast process, component size is limited by drum size. Cementation process
Carburising	Relatively cheap to develop but limited to steels in face centred cubic crystal form.	Extremely high hardness and wear resistant properties developed to appreciable surface depths. High temperatures limit the process and cause metal distortions.	Gas, solid or liquid processes make it versatile for different substrates	Wear parts, high hardness, limited to metals, namely steels, good depth of penetration.	Cyanide process is hazardous to life.	Samples can be masked if no heat treatment is required in certain areas of the surface, post heat treatment can be conducted on components.

Table 3. List of coating techniques and applications

5.0 General discussion and conclusions

Surface engineering technologies supply added value and thus profit. It acts as a bridge, transferring technology and expertise between end-user sectors that would not normally benefit from it. Surface Engineering continues to evolve, offering new opportunities for those involved in the research and applications of these coatings. Developing new coating methods to replace old techniques and applications will generate wealth and create new products for a wide range of industries. Surface engineering also represents a very efficient use of specialist materials. With a reduction in equipment costs, and improvement in knowledge and technical skills, the future research and development of surface engineering is promising. It is one key area where physicists, biologists and engineers have integrated knowledge and expertise to develop and apply successful solutions to dated technology. These advances, supported by environmental, health and safety, nanotechnology and designs will see lead to greater applications over the next 30 years.

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