

COATINGS

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Thermal Spraying and
Surface Engineering
Association



- Cold Spraying
- High-Performance Automotive Applications
- Conference Details
- TSSEA News

"quality coatings for engineers"

In this Issue

Articles

- Cold Gas Dynamic Spraying
- High-Performance Automotive Applications

Regular Features

- Members News
- Spring Conference
- Annual & Autumn Conferences

Cover Photograph

Plasma spraying a coating to the bore of an automotive lightweight cylinder block. The rotating extension is fed into the bore and the block remains stationary (photo courtesy of Sulzer Metco Limited)



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TSSEA News in Brief

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- In future back issues of "Coatings" will be available to members of the TSSEA via the web-site whilst non-members will be able to order issues through the secretary of the TSSEA.

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COLD GAS DYNAMIC SPRAYING

Dr Philip Shipway
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In recent years there has been a significant growth in the use of thermal spraying techniques to deposit wear, corrosion or oxidation resistant materials onto the surfaces of engineering components to allow them to function under extreme conditions. Much work has been done on developing air plasma spraying, vacuum plasma spraying and high velocity oxy-fuel spraying of a range of materials to obtain low porosity coatings, well bonded to the substrate. In all of these processes powder particles are injected into a hot gas jet, accelerated towards the substrate to be coated (reaching speeds of 200 - 600 m s⁻¹) and heated to a molten or softened state. A fundamental limitation of thermal spraying is that the powder must arrive at the substrate in at least a partially molten state in order to achieve good inter-particle bonding. This can lead to thermally activated phase changes in the powder (e.g. oxidation or secondary phase formation) which may ultimately degrade coating performance.

Over the years, the evolution of thermal spray processing technology has been directed towards achieving the **simultaneous** aims of increasing particle velocities whilst reducing particle heating to produce deposits with, amongst other things, high bond strengths, low porosity and reduced oxidation. A process developed in the former USSR in the late 1980's, known as cold gas dynamic spraying (CGDS) is now beginning to attract significant attention because it is capable of accelerating particles (generally less than 30 µm in size) up to speeds of 800 m s⁻¹ without heating them signifi-

cantly (driving gas temperatures between ambient and 400°C are common) by use of a high pressure supersonic gas jet. Fig. 1 shows a schematic diagram of a typical CGDS apparatus. The particles are accelerated by a gas stream passing through a de Laval type nozzle; helium or nitrogen are commonly employed as propellant gases, with the former allowing higher particle velocities to be achieved. Upon impact with a target (or an already building deposit), the particles plastically deform and bond well, allowing a very low porosity deposit to be rapidly built up. Fig. 2 shows micrographs

basic process was first patented in the USA in 1994 and it has subsequently been reported that a range of metallic powders can be deposited onto substrates with a very high deposition efficiency. Work to date has been largely empirical but nevertheless the significant potential of the process has been identified. Research has shown that it is possible to:

- spray reactive materials with little oxidation (thermal spray tends to oxidise such materials)
- preserve the phase state of the powder into the deposit

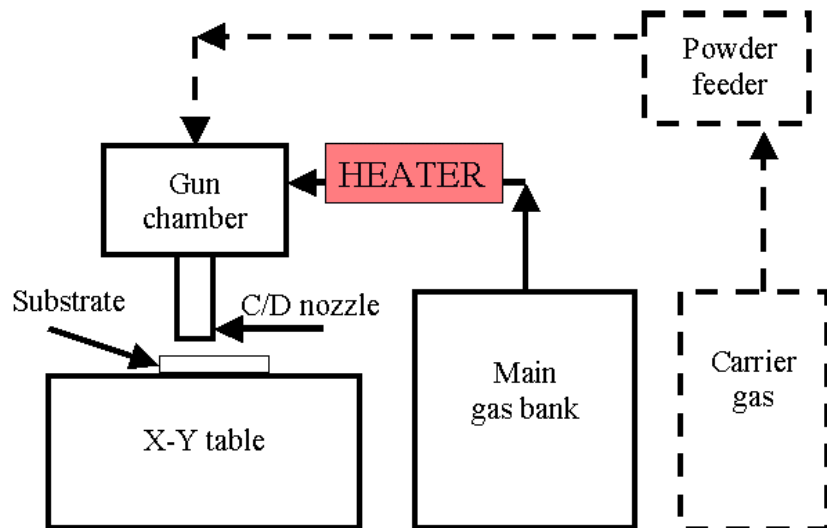


Fig. 1. Schematic diagram of CGDS apparatus

of an aluminium deposit on steel with evidence of low porosity and high deformation of the particles on impact. The etched structure in Fig. 2b shows high strains within individual particles. The boundaries have been delineated by the etch; the observed boundary structure is not oxide as is often observed in thermal spraying. The

(thermal spray often produces undesirable secondary phases)

spray on to heat sensitive materials and components. For instance, Sandia National Labs in the USA have repaired a heat sensitive satellite component

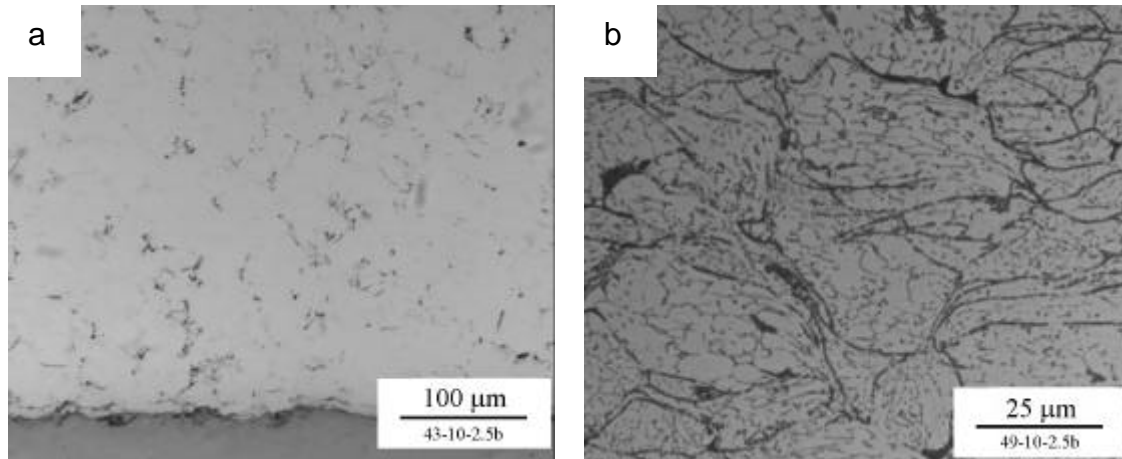


Fig. 2. Aluminium deposit on steel substrate: (a) unetched showing low porosity; (b) etched showing large particle strains. The etch has delineated grain boundaries and microsegregation within particles.

costing \$150 000 using CGDS, and claimed that without CGDS technology, the component would have been scrapped.

- deposit tracks with a narrow footprint, down to 2 mm or less in width.
- deposit with a traverse speed of up to 1 m s^{-1} (high potential cost saving in implementation)

Figure 3 shows an example of the microstructure of CGDS titanium. The structure shows a low oxide content despite the fact that titanium is a highly reactive material. In this particular deposit, porosity is evident, especially at the surface.

There currently exist in the open literature currently about fifty pa-

pers on CGDS. Much of the earlier work originated from Sandia National Labs in Albuquerque, New Mexico under the direction of Dr Mark Smith. Sandia National Labs continues to be a key player in this area of research and organised the first international meeting specifically on CGDS technology in Albuquerque, September 2002. Research in CGDS technology continues to be dominated by the USA, with large corporations such as Delphi and Pratt & Whitney involved in research and development alongside the government and university research. The other main focus of research worldwide is in Germany, where a successful team involving Linde Gas, CGT (a CGDS equipment manufacturer) and the University of the Federal Armed Forces in Hamburg has

been formed.

In the UK, research began in 2000. The first grant for University research in this area was awarded by the Engineering and Physical Sciences Research Council (EPSRC) to Dr Philip Shipway at the University of Nottingham. His research programme was entitled "Cold spray deposition for the manufacture of coatings and tracks". This was closely followed by an award to Dr Bill O'Neill at the University of Liverpool for a research programme entitled "Cold gas dynamic manufacturing". As a means of disseminating results from their research and outlining the capabilities of the process to a wider audience, an open one-day workshop, sponsored by TSSEA, was held on the 5th December 2002 at the University of Nottingham which was attended by over fifty people, the majority coming from interested industrial organisations. Presentations made at the event were as follows:

Dr Philip Shipway, University of Nottingham

Cold gas dynamic spraying: an international perspective

Dr Chris Sutcliffe, University of Liverpool

Cold gas dynamic manufacturing

Dr Jack Gabzdyl, BOC

Gas supply systems for cold gas

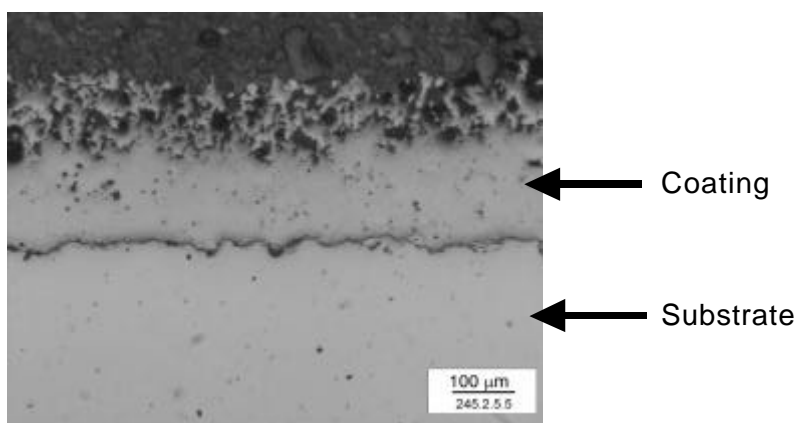


Fig. 3 Thin CGDS titanium deposit on mild steel substrate.

dynamic spraying

Prof Graham McCartney, University of Nottingham.

Cold gas dynamic spraying of coatings and tracks

The presentations highlighted that significant advances in understanding of the process have been made, along with development of novel applications, such as application of specialised coatings and direct deposition to build 3-D structures. One of the concerns has been the cost of the process. It is well known that use of helium as the driving gas for this process has many technical advantages over the use of nitrogen, such as high deposition rate and high deposit integrity. Moreover, Jack Gabzdyl of BOC argued the high apparent cost of helium resulted in net savings due to the increased process efficiencies. This can be further improved by the use of helium recycling, and a demonstration recy-

cling unit is being commissioned at present by BOC in collaboration with Dr O'Neill.

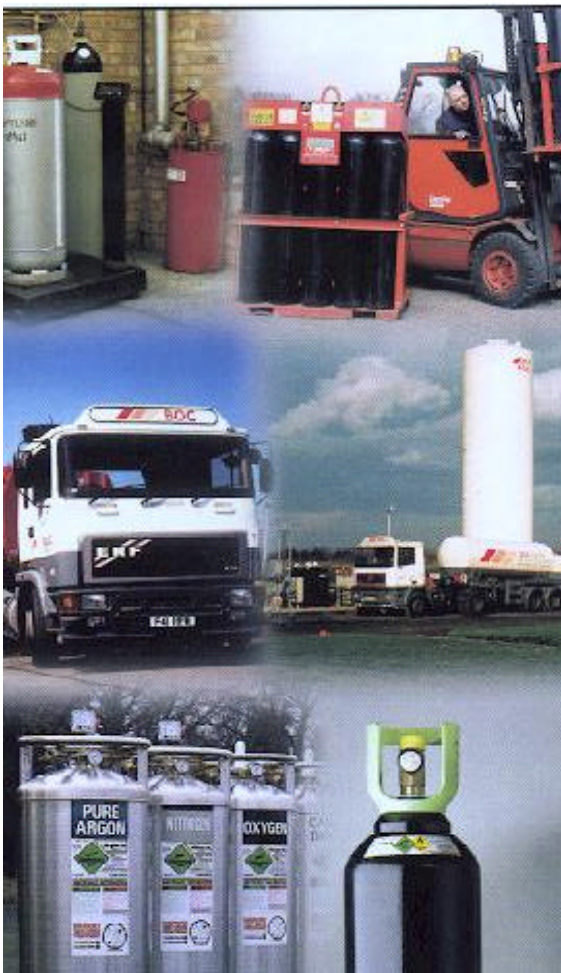
The interest in this field worldwide is leading to live commercial applications. In the United States, companies such as ASB Industries have the capability for CGDS. Hendry in California employ a process very similar to CGDS (known as *kinetic metallisation*) to deposit aluminium grounding strips onto telecommunication equipment racks. There are still many questions to be answered. Most of these centre around the mechanical properties of the deposits themselves (strength, ductility etc) and the deposit-substrate bond. To allow significant progress in these areas requires a more detailed understanding of the mechanism by which particles deform and bond; *in my opinion, this is the major scientific challenge in this area which will unlock the key to successful exploitation of the technology.* As

outlined earlier, the process does offer some significant advantages over other material deposition processes and it is only a matter of time before we begin to see CGDS as another commercially viable technique in the toolbox that is available to us.

For further information, please contact

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High-Performance Automotive Applications

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Important innovations on the racing circuit often become mainstream applications in the automobile industry. High-performance racing cars make extensive use of thermal spray, thin film technology, as well as plasma and gas nitriding/nitrocarburizing. In recent years, race teams have adapted the use of plasma-sprayed coatings to reduce friction, control high temperatures, and protect vehicle parts from wear and corrosion.

For many years, customers have turned to Sulzer Metco for technology solutions that are effective and profitable. As a global leader in surface engineering solutions and services, Sulzer Metco helps solve the surface technologies challenges faced by the automotive industry (Fig. 1).

Surface enhancement engineering basically changes the surface of a material by additive processes such as thermal spray, PVD (physical vapor deposition), CVD (chemical vapor deposition), plasma nitriding or nitrocarburizing (PNC – with or without oxidation) to deposit a thin film or coating that cost-effectively enhances the physical properties of the substrate (Fig. 2). In effect, this coating creates a new material superior to either one by itself.

Many Advantages of Thermal-sprayed Coatings

There are numerous advantages of



Figure 1 The automotive industry all over the world relies on Sulzer Metco coatings to reduce friction, wear, and corrosion.

surface engineered thermal sprayed coatings. They can be applied to almost any substrate with a reproducible coating quality. In comparison with painted coatings, no volatile organic compounds (VOCs) are emitted and no drying time is required. A broad range of coatings is available, and they can be deposited at a high rate on both small as well as large areas. The process imparts little heat to the substrate, thus avoiding distortion

of metal surfaces.

Reduced Engine Weight

Using advanced plasma spray technology, a thin (150- μm) coating can be deposited directly onto aluminum alloy cylinder bores, eliminating the need for cast iron or composite liners (Fig. 3). These coatings give many advantages, and the residual porosity in the coating helps to significantly re-

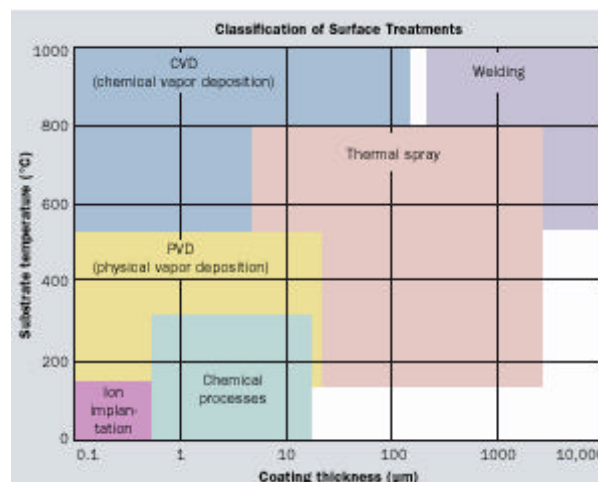


Figure 2 Surface treatments are classified depending on coating thickness and substrate temperature. Classification of Surface Treatments
 Substrate temperature ($^{\circ}\text{C}$)
 Coating thickness (μm)
 Ion implantation
 Chemical processes
 PVD (physical vapor deposition)
 CVD (chemical vapor deposition)
 Thermal spray
 Welding

Tailor-made Coatings

PVD thin-film surface coating technology and plasma-supported heat treatment technology provide customers with a flexible choice of friction, wear and corrosion protection.

Herewith some examples of properties that can be influenced:

- Tribological features, e.g. surface roughness and friction coefficient
- Coating hardness
- Heat conductivity
- Electrical insulation or conductivity
- Reduced adhesion of plastics, etc. to moulds
- Varied thickness and ductility
- Durable, decorative colors
- Anticorrosion

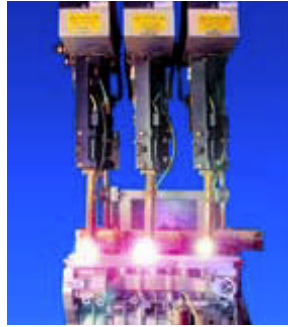


Figure 3 A triple plasma gun for the coating of cylinder bores of an automotive engine. The replacement of cast iron liners by plasma-sprayed coatings significantly reduces the friction, oil consumption and weight.

Numerous Automotive Applications

Race car engine parts that routinely receive thermal-barrier coatings and other surface engineered coatings include:

- Rocker arms and balls
- Piston domes and skirts
- Ring and pinion gears
- Cylinder heads and bores
- Combustion chambers
- Valve faces and stems
- Bearing races
- Exhaust ports and header
- Turbocharger housings
- Intake/exhaust manifold
- Differential plates
- Valve springs
- Skid plates

duce the coefficient of friction by using a micro-cavity lubrication system. Compared to cast iron liners, these micro-cavities extend the hydrodynamic lubrication area, leading to greater performance and reduced oil consumption. The wear resistance of these coatings is superior to cast iron, and the heat flow between the combustion chamber and engine block is much more predictable. The weight of the cylinder block, as well as the pitch distance between bores, is reduced.

Increased Efficiency

Plasma-applied thermal-barrier coatings promote greater combustion efficiency while protecting piston crowns, cylinder heads and other components against thermal degradation and detonation damage. These engineered coatings

help maximize engine performance by optimizing ignition advance, resulting in improved gas turbine technology and increased turbo-charger or supercharger boost efficiency. Special abrasion coatings on the charger housing are designed to be machined by the compressor or turbine wheel to give optimum clearance between static and rotating components. Increases in efficiency of up to 5% can be obtained when using this technology. Thermal-barrier coatings are also used on exhaust components and heat shields to minimize heat flow into the engine compartment and exhaust tunnel.

Coatings for Brake Discs

Thermally sprayed coatings have been successfully applied to lightweight metal matrix composite brake discs for high-performance

motorcycles and race cars. The performance benefits of a low-mass brake disc are greatly enhanced by a ceramic coating, resulting in an increased coefficient of friction, increased wear resistance and reduced transient temperature at the braking surface. The coated discs also work well under wet conditions. Race car, motorbike, go-kart and off-road vehicle builders and engineers report that thermal spray and PVD coatings are essential for high performance (Fig. 4). The coatings protect many parts or components in vehicles that are subject to heat, wear, friction, or corrosion. Many experienced racing teams attribute the lower maintenance, faster speeds and higher reliability of their vehicles to the benefits obtained from thermal spray and PVD coatings.

Figure 4 Innovative plasma coatings on cylinder bores make race car engines more effective.



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New spraying facility at TWI

The recent move of TWI's thermal spray laboratory into the new engineering facility has been complemented by the installation of a state-of-the-art dry particle extraction system specifically developed for the HVOF spraying process.

The extraction system features very high flow rates of 20,000m³/hour and high face velocities to improve the extraction efficiency of high velocity overspray particles and the high heat generated by the HVOF process.

TWI has four commercial HVOF systems: Diamond Jet, JP5000, TopGun and HV wire, which are available to TWI Industrial Members for independent process studies and application development.

The HV wire system has recently been used on TWI's core research programme to look at depositing metallic coatings (aluminium, stainless steel and nickel based alloys) onto steel substrates for corrosion protection. The HV wire process is ideally suited to on-site applications as it is simple to operate and light weight.



To find more out about the thermal spraying activities at TWI, please contact Andy Sturgeon or Dave Harvey

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Investigation of coating failure - a TWI service

In all industries, coatings are widely used to provide protection against wear and corrosion damage. In most cases the coating performs as expected, but when failure does occur, it is necessary to understand the reasons quickly so remedial action can be taken. Such failure could be due to unexpected changes in the service environment, inappropriate coating selection or a poor standard of coating application.

At TWI, professionally qualified staff with expertise in coating processes and applications, metallurgists and corrosion experts, provide the multi-disciplinary experience needed to solve coating failure problems. We can help determine the cause of failure by providing materials analysis, metallography, renovation and repair, advice on coating selection and expert witnesses.

In addition TWI has a unique range of coating facilities, in particular thermal spraying, laser and arc welded cladding together with a wide range of mate-



rials analysis, adhesion testing, corrosion testing and inspection facilities.

If you have a coating failure problem or would like to find out more about the thermal spraying activities at TWI please contact Andy Sturgeon or Dave Harvey. E-mail: andrew.sturgeon@twi.co.uk or dave.harvey@twi.co.uk

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TSSEA 2003 Programme

Spring Conference 2003

The Versatility of thermally sprayed coatings in the Engineering Industry

To be held on 25th April 2003
 The Welding Institute Ltd.,
 Aurora Court,
 Barton Road,
 Riverside Park
 Middlesbrough

Options for coatings.

There are now many surfacing technologies for either repair or improvement coatings for components or structures available to engineers.

The versatility of the thermal spraying processes is unique in that there is a wide range of materials for coating to choose from (any material which has a melting point) and there is no limit to the size or quantity of components which may be treated. Using hand operated preparation equipment and light-weight spraying guns no steel structure is too large to be treated. For one off repair applications, cylindrical components may be held in conventional machine tools, rotated and the spraying gun traversed so that an even coating may be applied.



Plasma spraying a coating to the bore of an automotive lightweight cylinder block. The rotating extension is fed into the bore and the block remains stationary. (photo by courtesy of Sulzer Metco Limited)

For batch or production quantities special purpose machines for component handling, combined with programmed robotic gun manipulators, are now commonplace, enabling coatings to be applied with the highest possible level of quality control. Although spraying may be regarded essentially as a "line of sight process" there are instances where customised spraying devices are available to treat small internal diameters where the component need not be moved during treatment. A classic example of this is described in one of the presentations at this conference.

Different coating characteristics may be achieved not only by the choice of material, but also by varying the operating parameters. Normal wear resistant coatings are achieved by applying materials such as Tungsten Carbide, using optimum parameters to ensure the 'best' coating characteristics, such as maximum inter particle cohesion and density. However abrasible coatings used in the aerospace industry need to combine a degree of erosion resistance with minimum resistance to the cutting action of a fast rotating component when an interference occurs. This is achieved with specially engineered coating materials and carefully prepared operating parameters.

In addition to providing coatings for mechanical components, thermal spraying is also used for the protection of iron and steel structures against corrosion. Coatings of zinc, aluminium or their alloys are commonly used to protect such structures as bridges and offshore plat-



Hand spraying Zinc for corrosion protection using electric arc equipment. (photo courtesy of Thermion U.S.)

forms, where the most arduous and aggressive conditions are experienced. Such protection is afforded by the sacrificial action of these materials besides conferring barrier protection.

The programme today provides yet another variation in the use of sprayed coatings of Zinc, this time on concrete structures. In this case a coating of Zinc is sprayed on to the exterior of the concrete structure e.g bridges, to provide a secondary anode for an impressed current to be conveyed to protect the reinforcing bars.

Full details of timings and presentation titles will be issued on the day.

Conference Dates for 2003

Spring Conference

"The versatility of thermally sprayed coatings in the Engineering Industry"

To be held on 25th April 2003 at TWI Ltd., Aurora Court, Barton Road, Riverside Park, Middlesbrough

Programme:

Dr Sai Gu (Aston University, Birmingham) - "Thermal Spray Modelling - Uncovering the Nature of process"

Dr. M. Gee (National Physical Laboratory) - "Measurement and Characterisation of Coatings"

Professor G. McCartney/ Dr . P Shipway (University of Nottingham) - "Cold Spraying"

Mr. D. Harvey (TWI) - "Sprayed Coatings on Concrete Structures"

Dr.T Lester (Metallisation Limited) - "Coatings on Concrete Structures"

Mr.R.Bowen(Praxair TAFE Technologies) - "Engineering Coatings"

Dr. P.Chandler (C.A.Technology) - "Overview and Thickness Measurements"

Mr R. Bowles (Barrier Limited Newcastle on Tyne) = "Thermally Sprayed Coatings to protect off shore structures from corrosion."

Annual Conference

The Annual Conference will be held on the 16th July 2003 at Beaumanor Hall Woodhouse Leicestershire.

More details will be announced later in the next edition of "Coatings" and on the web TSSEA site.



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Autumn Conference

The autumn Conference will be held on Thursday 11 November 2003. More information will be available shortly and will be posted in "Coatings" and on the TSSEA web site.