In The News

New Literature

COR·SUR for Windows Corrosion Data Software

Price: $280 (NACE members: $230)

The process of materials selection is often tedious and time-consuming. With COR·SUR and COR·SUR2 for Windows you have a quick and easy method for screening materials for possible use in a given environment.

The information contained in COR·SUR and COR·SUR2 for Windows is organized to enhance its usefulness as a tool for materials selection. It is concerned with the corrosion behavior of engineering materials. The tables, charts, and graphs contained in these software programs provide a cost-effective method for reducing the field of choice of materials of construction for particular applications quickly, based on corrosion behavior. COR·SUR and COR·SUR2 were originally derived from information contained in *Corrosion Data Survey, Metals Section* and *Corrosion Data Survey, Nonmetals Section.* Since the original software release, many improvements and updates have been incorporated into the software programs. The software programs document the performance of 71 materials in more than 1850 environments and provide a ready reference for evaluating the suitability of materials for possible use.

System requirements: IBM-compatible PC with 386 (486 or higher recommended) processor; Windows 3*x* or higher; 8 MB RAM (16 MB for Windows 95); 10 MB hard disk space; Color graphics board for viewing graphics.

Contact: NACE Membership Services, P.O. Box 218340, Houston, TX 77218-8340; tel: 281/228-6223; fax: 281/228-6300; e-mail: msd@mail.nace.org; on-line: www.nace.org.

Cambridge Materials Selector; a Guide to Materials Selection for Engineering Education

The optimum selection of materials is becoming increasingly important for innovation in engineering design and an increasingly important part of engineering education. Two of the main difficulties with teaching materials selection are having a suitable methodology to enable optimum materials choice for particular design requirements and providing sufficient high-quality property data for the 80,000 or so materials available to engineers.

Professor M. Ashby and his team at the Engineering Department of Cambridge University have developed a system that links the properties of engineering materials directly with functionality of a particular design. The method is described in the textbook *Materials Selection in Mechanical Design* by Ashby and published by Butterworth Heinemann.

This methodology is now embedded into an integrated software package specifically designed for use in engineering education. The Cambridge Materials Selector is a Windows-based PC software toolkit that combines the use of graphical materials selection charts and extensive databases of material properties to enable the optimum selection of materials. The databases contain all the main classes of engineering materials including metals, polymers, ceramics, elastomers, and composites. More than 50 properties are stored for each material, including mechanical, thermal, electrical, price, forming and joining methods, typical uses, and suppliers.

Using the Cambridge Materials Selector provides:

- An understanding of the properties of engineering materials and their role in design
- An extensive data source for all classes of engineering materials
- A cost-effective computer-based system easily used for student labs and workshops, with single- or multi-user software licenses
- A toolkit for undergraduate teaching together with a versatile platform for project work

Contact: Granta Design Ltd., Trumpington Mews, 40B High St., Trumpington, Cambridge CB2 2LS, U.K.; tel: +44 1223 518895; fax: +44 1223 506432; e-mail: sales@granta.co.uk; web: http://www.granta.co.uk.

"TS-nano'99" Thermal Spray Processing of Nanoscale Materials

15-20 August 1999
Quebéc City, Canada

Conference Overview

Significant interest has been generated in the field of nanoscale materials. This interest stems not only from the outstanding properties that can be obtained in such materials, but also from the advent that high-quality, unagglomerated nanoscale powders can be manufactured in large industrial size quantities.

However, it was recognized early on that for this field to really mature, rapid and large-scale industrial applications were required and that for this to happen, several major problems needed to be solved. First, there was the difficulty of the large-scale production of materials, then there was the need to process these powders to be densified without the loss of their nanostructures to obtain bulk products. There are many methods available to form nanocrystalline materials that can be further processed to evolve nanophase and or nanocrystalline structures. Some of these materials are becoming fully commercialized and, accordingly, the focus is shifting from synthesis to processing, that is, how to make useful coatings and structures from these powders. The potential applications span the whole spectrum of technology, for example, from thermal barrier coatings for turbine blades to wear-resistant rotating parts. The processing step includes thermal spray methods such as HVOF and plasma spray, but also includes innovations such as chemical vapor condensation (CVC) and a number of exciting new combustion processes.

The conference format will include state-of-the-art review presentations, oral and poster presentations. Industrial examples and technical input are strongly encouraged, as are poster and tabletop displays. Student and postdoctoral scholarships will be available to enable their participation.

Conference Objective

The objective of this conference will be to assess the state-of-the-art in understanding the science and technology of thermally sprayed nanocrystalline coatings. The conference aims to address the synergism between processing, physical and mechanical characteristics, and the behavior of these novel materials. Areas of interest include, but are not limited to:

- Innovations in processing
- Process modeling and diagnostics
- Microstructure and mechanical property characterization
- Measurement, analysis and modeling of equipment and deposits
- New equipment and processes
- Nanostructured coatings
- Case histories and practical experience with forming nanostructured materials
- Applications and industrial issues
- Poster sessions
- Tabletop displays from companies and industries.

Authors are strongly encouraged to contact the conference organizers with potential focus areas that can be considered for inclusion in this meeting.

Conference Publication

Written versions of the Extended Abstracts will be compiled into a collection of papers that will be published as the proceedings of the conference. This extended paper will be published in the *Journal of Thermal Spray Technology* and, as such, will contribute to the archival literature base for this important area of science and technology.

Submission of Abstracts

Abstracts can be submitted to any of the conference chairmen or through the web site of the Engineering Foundation.

Tentative Schedule

30 October 1998

Send letter of intent by e-mail to cberndt@notes.cc.sunysb.edu. Include a prospective paper/poster title and a short one-paragraph description of the presentation. Include full contact details (postal address, telephone, fax, and e-mail) of the author for all correspondence. Also submit the attached application form separately to the Engineering Foundation.

31 January 1998

Send a two page extended abstract (including some figures and references) to C.C. Berndt.

28 February 1999

Notification of acceptance.

31 March 1999

Deadline for applications for those not submitting abstracts.

30 June 1999

Preparation of Pre-Conference Booklet of Abstracts.

Conference Chairs

The conference is being organized and cochaired by:

Dr. Christopher C. Berndt, Professor
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1-4 November 1999, Cincinnati, Ohio

"Intermetallics for the Third Millennium," a Symposium Dedicated to Prof. R.W. Cahn

The Intermetallic Materials Committee and Specialty Materials Sector of ASM International are sponsoring The International Symposium on "Intermetallics for the Third Millennium" being held in honor of Robert W. Cahn on his 75th birthday. This symposium will be part of the 1999 ASM Complete Metals and Materials Experience.

The symposium will address monolithic and multiphase intermetallics and their composites. Of particular interest will be fundamentals of alloy design; electrical, physical, and thermal properties, recovery, recrystallization, and grain growth; tensile, compressive, impact, creep, relaxation, fatigue, and bend strengths; and novel and conventional processing techniques. Prediction of evolving intermetallic systems based on first principles with an emphasis on "intermetallics of the future" are highly encouraged.

The symposium will consist of both invited and contributed papers.

Abstracts should contain no more than 150 words and any relevant graphs, charts, or other support data. Please indicate the topic for which the abstract is being submitted; the proposed title, conclusions, and significance of the paper; three (3) keywords from your paper for indexing purposes; and the following information about the author and all coauthors: name, title, company/affiliation, complete address, phone and fax number, and e-mail address. Please underscore the name of the individual presenting the paper.

Also, the abstract is to be accompanied by a completed "Program Content Selection Guide" available from: www.asm-intl.org or from Derek Weston, ASM International; 440/338-5151; e-mail dweston@po.asm-intl.org.

Co-Organizers: Dr. S.C. Deevi

Dr. C.T. Liu, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN USA.

Prof. M. Yamaguchi, Department of Materials Science and Engineering, Kyoto University, Yoshida Honmachi Sakyo-Ku, Kyoto Japan.

Send abstracts to: Dr. S.C. Deevi, Research and Development Center, Philip Morris USA; 4201 Commerce Rd., Richmond, VA 23234, USA; tel: 804/274-4968; fax: 804/274-4778; e-mail: deevi@talos.pm.com.

To submit abstract on-line: Visit the ASM International Website at www.asm-intl.org and click on Conferences and Education. Follow the instructions provided to prepare and submit your abstract on-line.

13-18 June 1999, Beijing, China

Surface Engineering Symposium at the Fifth IUMRS International Conference on Advanced Materials

The International Union of Materials Research Societies has chosen Beijing for the site of its Fifth IUMRS International Conference on Advanced Materials. C-MRS will follow the footprints of the E-MRS, MRS-Japan, and MRS-Mexico, the organizers of the four previous conferences, to make it a success. Because this is the last IUMRS-ICAM in this century, it is the intention of the IUMRS to design it in a rather comprehensive way and to make it a forum to give a forward look to materials science while striding into a new century.

Main topics of the symposium on surface engineering include: characteristics and structure of surface layer; wear and antifriction technology—laser, electron beam, ion beam techniques, and advanced coatings; thermal spraying and welding; anticorrosion technologies; surface testing technology and theoretical analysis.

Symposium Organizers: K. Zhou, Guangzhou Research Institute of Nonferrous Metals, Wushan Guangzhou 510651 China; tel: +86-20-85231729-6203; fax: +86-20-85231605; e-mail: gzrinm@public.guangzhou.gd.cn

L. Wen, Institute of Metal Research, Chinese Academy of Sciences, Wenhua Rd., Shenyang, 110015, China; tel: +86-24-3843531-55564; fax: +86-24-3891320; e-mail: lswen@imr.ac.cn

For more information on the IUMRS-ICAM-1999, contact: Secretariat, IUMRS-ICAM-1999, C-MRS Office, 7 Baishiqiao Rd., Beijing, 100081, China; tel/fax: +86-10-68428640; e-mail: cmrssec@public.bta.net.cn

Prof. H. Li, Department of Materials Science and Engineering, Tsinghua University, Beijing 100084, China; tel: +86-10-62785775; fax: +86-10-62771160; e-mail: lhd-dms@mail.tsinghua.edu.cn

Dr. Y. Han, Beijing Institute of Aeronautical Materials, Beijing 100095, China; tel: +86-10-62458053 or 86-10-62452103; fax: +86-10-62456925 or 86-10-62456212; e-mail: hanyf@public.east.net.cn.

News from the GTS

The GTS (Gemeinschaft Thermisches Spritzen)

Among the group of surface coating technologies, thermal spraying offers the widest applications and can therefore be found in all sectors of industry and trade. Users of thermal spraying work on a wide range of levels and can be split into three groups:

- Internal production: Users add value to their products by in-house thermal spraying
- Service companies: Companies offer contract thermal spraying services. They use one or two process areas or even several processes.
- Research and development in the industry itself or in universities and academies: This target group is in third place in terms of the number of spraying systems in use.

The interests of these three groups of users of thermal spraying naturally differ a great deal. Therefore, this situation presented an ideal opportunity to get together the various types of companies and institutes and form an association to promote thermal spraying and undertake joint activities. The leading representatives of this expanding sector of industry within surface finishing technology met at special meetings and founded the Thermal Spraying Association (GTS). This association is intended to secure the long-term survival of its individual members in the thermal spraying sector within the hard and extremely competitive market for surface finishing technology.

The Aims of the GTS

The Thermal Spraying Association (GTS) was founded on 22 October 1992 by 13 companies after thorough and intensive preparatory work.

The GTS logo was designed and registered. The GTS is an association that is open to all users and supporters of thermal spraying throughout Europe. The primary aims of the founders of the GTS were to publicize the technology of thermal spraying to a wide industrial public, to promote thermal spraying in conjunction with the German Association for Welding Engineering (DVS) in practice and research, and finally to provide all its members with assistance in the industrial marketing of this technology. The joint activities of the GTS are designed to represent the market interests of its members and to establish these interests where necessary. The primary aims in this respect is the high quality of the coatings and appropriate quality assurance.

From the very beginning it was clear that securing the high level of thermal spraying technology could not be achieved solely by the general certification of member companies by state or state-accredited institutions in the sense of DIN EN ISO 9000 ff. Therefore, a GTS certificate was created together with an extensive range of regulations.

GTS document GTSPA001 forms the basis of the association and its statutes. The "GTS Quality Management Guideline" (GTSPA003) describes what GTS regards under the term quality assurance. There are currently a total of 17 GTS documents that have been defined and established. They guarantee that the association's activities are regulated, including the certification procedures for its members.

The Organization of the GTS

The activities of the GTS are regulated by the latest GTS statutes and other supplementary GTS-specific documents. The individual members determine the direction and procedure of the GTS at annual general meetings. The Executive Board elected at these meetings represents the GTS in its dealing with outside bodies and authorities.

The five-person Executive Board of the GTS is elected by the members for a term of two years. The Executive Board also includes the Chairman of the Quality Committee. This committee is responsible for ensuring that the regulations for GTS certification are drawn up and monitored in accordance with the statutes and for completing the actual certification procedure.

Contact: Geschäftsstelle der GTS; c/o Linde AG, Werksgruppe Technische Gase; P. Heinrich (Chairman), Seitnerstr. 70, 82049 Höllriegelskreuth; tel: ++49 (0) 89 74 46 1428; fax: ++49 (0) 89 74 46 1659; e-mail: gts_ev@compuserv.com; web: http://ourworld.compuserve.com/homepages/gts_ev.

Recent Conferences

SSPC98 International Conference and Exhibition

15-19 November 1998, Orlando, Florida

Session on "Thermal Spray: Some Like It Hot"

Chair: J. Costa, Corrosion Restoration Technologies, Jupiter, FL

- Thermal Spray Aluminum for Corrosion Protection—Some Practical Experience in the Offshore Industry, by R. Avery, Dynamic Coatings Corp., Houston, TX
- Restoration of the Historic Trenton Bridge Using Field Applied Thermal Spray Coatings, by A. Tsourous, Jupiter Painting Contracting Company, Inc., Croydon, PA
- High Output Arc Spraying—What Wire and What Pattern? by E. Sampson and W.R. Kratochvil, TAFA Inc., Concord, NH
- Corrosion Resistance of Zinc/Aluminum Alloy Coatings, by D.J. Varacalle, Jr., Idaho National Engineering Laboratory, Idaho Falls, ID; W. Zanchuck, E. Sampson, and W.R. Kratochvil, TAFA Inc., Concord, NH; K.W. Couch and D. Benson, Protech Laboratories Corp., Cincinnati, OH; and G.S. Cox, ITI Anti-Corrosion, Inc., Houston, TX
- Ski Lift Maintenance: A New Cost-Effective Approach, by M. Bhusari and R. Mitchner, TAFA Inc., Concord, NH

Contact: SSPC: The Society for Protective Coatings, 40 24th St., Sixth Floor, Pittsburgh, PA 15222-4656; tel: 412/281-2331; fax: 412/281-9993; web: www.sspc.org.

Arc Spray News from Sulzer Metco

One simple way to convince customers of a new product is to install it with them and let them use it. But Sulzer Metco raised its eyebrows when one customer (Folla Tech A.S. in Norway) agreed and announced its intention of spraying a coating 2.5 mm thick onto a roller 12 m long and 1.2 m in diameter with the equipment placed at its disposal. This ambitious target compelled the specialists of Sulzer Metco to make sure that everything went perfectly.

Success from the Start

The equipment involved was a SmartArc spraying facility with long-life contact tips, while the spraying material was an aluminum-bronze wire of 1.6 mm diameter supplied in 15 kg coils. Per hour, 11.4 kg of wire was sprayed, altogether 820 kg within 72 hours. The equipment was operated at a current level of 350 A. While the coils were being changed, the spray gun was cleaned with compressed air, and the contact tips, of which three pairs were being used, were changed and tested. At the end of the coating process, no wear could be seen on the tips. After changing the wire coils, spraying was resumed straight onto the roller surface.

The coated roller was part of a machine making endless wire screens for paper machines. The same type of roller was previously coated using a conventional arc spraying system. In comparison, the roller coated by the SmartArc process showed a much smoother, more uniform surface, which greatly impressed the customer.

Subsequently, Folla Tech coated a press roll 5 m long and 1 m in diameter without any problems (Fig. 1), which had previously been hard-chrome-plated. A Metcoloy 2 coating 1.7 mm thick was deposited, which was ground down to 1.3 mm with a belt-grinding machine. The R_a roughness attained was 0.27 μm. Previously, the operator had to send the roller to Austria each time for chromium plating. Next time, Folla Tech intends to renew the coating without dismantling the roll, on the actual paper machine.

Versatile Coating Technique

In the SmartArc process, the ends of two metal wires are guided together so that an electric arc is struck. The metal melts and then is atomized with the help of an air jet and accelerated onto the surface being coated. Here, the sprayed particles cool and form a bond with the substrate material. Depending on the wire material, coatings are formed resisting heat, wear, or corrosion. Special wires (SmartWires) are used for spraying. The coating thickness depends on the function of the layer and the spraying material and may range from 0.5 to well above 10 mm. To quote one example, a material containing 26% Cr was sprayed 10 mm thick onto a Kaplan turbine to protect it against abrasion.

Pseudoalloys can be deposited also by feeding two different wire materials. In this way, for example, a wear-reducing material, embedded in a heat-conducting matrix, can be deposited.

Optimal Air Flow

One of the special features of the SmartArc system is the optimal air flow, based on fluid dynamic investigations by Sulzer Innotec, which ensure very high arc stability and uniform melting, 360° around the arc. A large-volume air flow can be obtained at low pressures. In contrast to previous sprayed coatings, this enables high bonding strength and better coating quality to be obtained.

The wire feed has been greatly developed based on continuous monitoring and control of the wire feed motor torque (one motor in the gun and the control system) using a patented microprocessor motor control system. This has led to an outstanding long-time stability. In this way, the usage of spray material, wear parts, and energy has been reduced, with a beneficial effect on operating costs.

The arrangement of the wire feed has been designed to allow automatic spraying with robot manipulation of the wire gun (Fig. 2).

Article by Andrew Nicoll, *Sulzer Tech. Rev.*, Feb 1998, p 4-5. For more details: Sulzer Metco Holding AG, Andrew R. Nicoll, Rigackerstrasse 16, CH-5610 Wohlen, Switzerland, tel: +41 (0) 56-618 81 48; fax: +41 (0) 56-618 81 01; e-mail: andrew.nicoll@sulzer.ch.

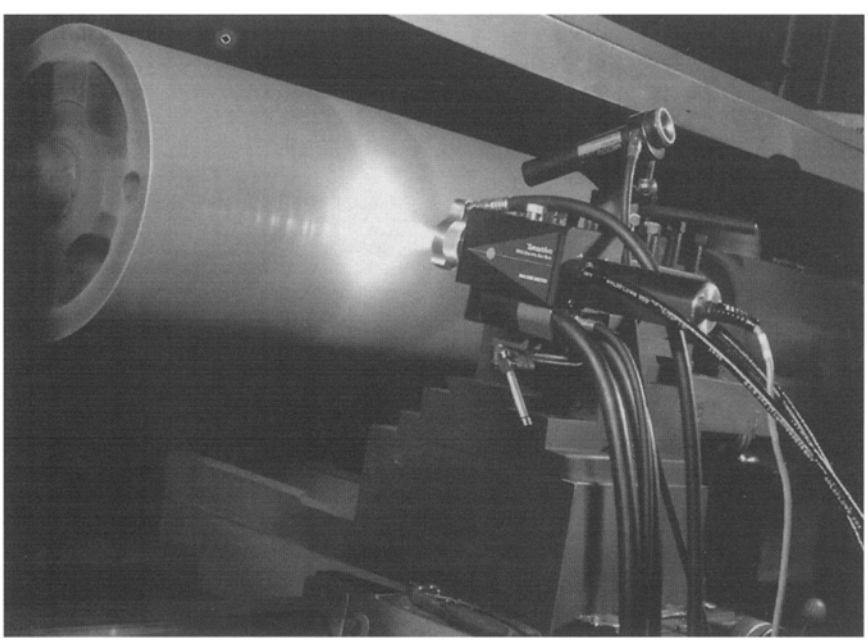


Fig. 1 Coating a roller using SmartArc—the new Sulzer Metco high-performance arc wire spray process

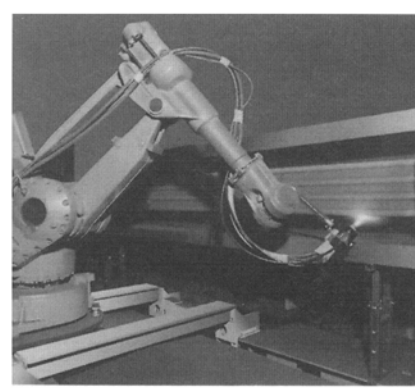


Fig. 2 For the first time, metallic surface coatings can be deposited with SmartArc using a robot mounted arc wire spray gun

Standard Methods to Measure Coating Thickness

Have you ever wondered about the many *standard methods* that are available to measure the thickness of a coating? The researchers at the EPMA Swiss Federal Labs in Thun,Switzerland, have compiled the following list from their massive database on "Thermal Spray Coatings." Contact Dr. S.D. Siegmann for further details; e-mail: stephan.siegmann@epma.com.

1.	ASTM	B 487	Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of a Cross Section
2.	ASTM	B 659	Measuring Thickness of Metallic and Inorganic Coatings
3.	ASTM	F 95	Test Method for Thickness of Lightly Doped Silicon Epitaxial Layers on Heavily Doped Silicon Substrates Using an Infrared Dispersive Spectrophotometer
4.	DIN	50436	Testing of semiconducting inorganic materials; measurement of the metallurgic thickness of epitaxial layers of silicon by the stacking fault method
5.	DIN	50437	Testing of semiconductive inorganic materials; measuring the thickness of silicon epitaxial layer thickness by infrared interference method
6.	DIN	50933	Measurement of coating thickness by differential measurement using a stylus instrument
7.	DIN	50948	Measurement of coating thickness; split-beam method
8.	DIN	50978	Testing of metallic coatings; adherence of hot dip zinc coatings
9.	DIN	50982-3	Principles of coating thickness measurement; selection criteria and basic measurement procedures
10.	DIN	50986	Measurement of coating thickness; wedge cut method for measuring the thickness of paints and related coatings
11.	DIN	50987	Measurement of coating thickness by the x-ray spectrometric method
12.	DIN EN	22063	Metallic and other inorganic coatings—Thermal spraying—Zinc, aluminum and their alloys (ISO 2063:1991); German version EN 22063:1993
13.	DIN EN ISO	1463	Metallic and oxide coatings—Measurement of coating thickness—Microscopical method (ISO 1463:1982); German version EN ISO 1463:1994
14.	DIN EN ISO	2064	Metallic and other nonorganic coatings—Definitions and conventions concerning the measurement of thickness (ISO 2064:1980); German version EN ISO 2064:1994
15.	DIN EN ISO	2177	Metallic coatings—Measurement of coating thickness—Coulometric method by anodic dissolution (ISO 2177:1985); German version EN ISO 2177:1994
16.	DIN EN ISO	2178	Nonmagnetic coatings on magnetic substrates—Measurement of coating thickness—Magnetic method (ISO 2178:1982); German version EN ISO 2178:1995
17.	DIN EN ISO	2360	Nonconductive coatings on nonmagnetic basis metals—Measurement of coating thickness—Eddy current method (ISO 2360:1982); German version EN ISO 2360:1995
18.	DIN EN ISO	2361	Electrodeposited nickel coatings on magnetic and nonmagnetic substrates—Measurement of coating thickness—Magnetic method (ISO 2361:1982); German version EN ISO 2361:1995
19.	DIN EN ISO	3543	Metallic and nonmetallic coatings—Measurement of thickness—Beta backscatter method (ISO 3543:1981); German version EN ISO 3543:1994
20.	DIN EN ISO	3868	Metallic and other nonorganic coatings—Measurement of coating thicknesses—Fizeau multiple-beam interferometry method (ISO 3868:1976); German version EN ISO 3868:1994
21.	DIN EN ISO	3882	Metallic and other nonorganic coatings—Review of methods of measurement of thickness (ISO 3882:1986); German version EN ISO 3882:1994
22.	DIN EN ISO	4518	Metallic coatings—Measurement of coating thickness—Profilometric method (ISO 4518:1980); German version EN ISO 4518:1995
23.	DIN EN ISO	8401	Metallic coatings—Review of methods of measurement of ductility (ISO 8401:1986); German version EN ISO 8401:1994
24.	DIN EN ISO	9220	Metallic coatings—Measurement of coating thickness—Scanning electron microscope method (ISO 9220:1988); German version EN ISO 9220:1994
25.	DIN V ENV	1071-1	Advanced technical ceramics; methods of test for ceramic coatings; part 1: determination of coating thickness by contact probe profilometer; German version ENV 1071-1:1993
26.	DIN V ENV	1071-2	Advanced technical ceramics; methods of test for ceramic coatings; part 2: determination of coating thickness by the cap grinding method; German version ENV 1071-2:1993
27.	DVS	2303-1	Zerstörungsfreies Prüfen von thermisch gespritzten Schichten,Schichtdickenmessung
28.	EN ISO	1463	Metallic and oxide coatings—Measurement of coating thickness—Microscopical method (ISO 1463:1982)
29.	EN ISO	2064	Metallic and other nonorganic coatings—Definitions and conventions concerning the measurement of thickness (ISO 2064:1980)
30.	EN ISO	2177	Metallic coatings—Measurement of coating thickness—Coulometric method by anodic dissolution (ISO 2177:1985)
31.	EN ISO	2178	Nonmagnetic coatings on magnetic substrates—Measurement of coating thickness—Magnetic method (ISO 2178:1982)
32.	EN ISO	2360	Nonconductive coatings on nonmagnetic basis metals—Measurement of coating thickness—Eddy current method (ISO 2360:1982)
33.	EN ISO	2361	Electrodeposited nickel coatings on magnetic and nonmagnetic substrates—Measurement of coating thickness—Magnetic method (ISO 2361:1982)
34.	EN ISO	3543	Metallic and nonmetallic coatings—Measurement of thickness—Beta backscatter method (ISO 3543:1981)
35.	EN ISO	3868	Metallic and other nonorganic coatings—Measurement of coating thicknesses—Fizeau multiple-beam interferometry method (ISO 3868:1976)
36.	EN ISO	3882	Metallic and other nonorganic coatings—Review of methods of measurement of thickness (ISO 3882:1986)
37.	EN ISO	4518	Metallic coatings—Measurement of coating thickness—Profilometric method (ISO 4518:1980)
38.	EN ISO	9220	Metallic coatings—Measurement of coating thickness—Scanning electron microscope method (ISO 9220:1988)
39.	ENV	1071-1	Advanced technical ceramics; methods of test for ceramic coatings; part 1: determination of coating thickness by contact probe profilometer
40.	ENV	1071-2	Advanced technical ceramics; methods of test for ceramic coatings; part 2: determination of coating thickness by the cap grinding method
41.	ISO	1463	Metallic and oxide coatings; measurement of coating thickness; microscopical method

(continued)

Standard Methods to Measure Coating Thickness (continued)

42.	ISO	2064	Metallic and other inorganic coatings—Definitions and conventions concerning the measurement of thickness
43.	ISO	2177	Metallic coatings; measurement of coating thickness; coulometric method by anodic dissolution
44.	ISO	2178	Nonmagnetic coatings on magnetic substrates; measurement of coating thickness; magnetic method
45.	ISO	2360	Nonconductive coatings on nonmagnetic basis metals; measurement of coating thickness; eddy current method
46.	ISO	2361	Electrodeposited nickel coatings on magnetic and nonmagnetic substrates; measurement of coating thickness; magnetic method
47.	ISO	2808	Paint and varnishes; determination of film thickness
48.	ISO	3497	Metallic coatings; measurement of coating thickness; x-ray spectrometric methods
49.	ISO	3543	Metallic and nonmetallic coatings; measurement of thickness; beta backscatter method
50.	ISO	3868	Metallic and other nonorganic coatings; measurement of coating thicknesses; Fizeau multiple-beam interferometry method
51.	ISO	3882	Metallic and other nonorganic coatings; review of methods of measurement of thickness
52.	ISO	4518	Metallic coatings; measurement of coating thickness; profilometric method
53.	ISO	8401	Metallic coatings; review of methods of measurement of ductility
54.	ISO	9220	Metallic coatings; measurement of coating thickness; scanning electron microscope method
55.	JIS	H 8401	Methods of thickness measurement for thermal spraying coatings

Industrial News

Howmet Expands Machining Operation

Howmet Corporation's Winsted Machining operation today announced the completion of the first phase of its expansion. "We have installed four new five-axis, computer-controlled cubic boron nitride machines to create a state-of-the-art machining center. This center has increased our ability to meet the market's demand for one-stop shopping for ready-to-assemble components," says James R. Stanley, senior vice president, U.S. operations. "Today customers want to deal with fewer suppliers and receive finished components on a just-in-time basis, delivered right to the point of use."

Howmet has invested approximately $3 million to complete phase one of its expansion at the Winsted Machining operation. This investment represents the first of three equally funded phases.

Howmet is making these investments to reduce dependency on outsourcing for ancillary operations such as heat treating and laser-hole drilling. "Customers are demanding their parts faster, so we are targeting unprecedented reductions in cycle time," says Elmer Miller, general manager of the machining operation. "Moving as many operations as possible under our roof gives us the flexibility to make aggressive delivery commitments, then live up to them."

Contact: Doreen Deary, Howmet Corporation, 475 Steamboat Rd., Greenwich, CT 06836-1960; tel: 203/625-8735; fax: 203/625-8796.

Howmet Invests $1.75 Million to Install New Furnace

Howmet Corporation's Hampton Casting operation today announced plans to expand its directional solidification (DS) capabilities by installing a new furnace. The $1.75 million investment is a response to strong demand in the industrial gas turbine (IGT) sector. This is the first investment in an overall plan which Howmet is now reviewing with the city of Hampton. The plan includes a potential investment of $30.5 million in plant and equipment over the next three years. Investments at this level may require an addition of up to 143,500 square feet of plant and generate up to 196 new jobs.

The increase in demand in the IGT sector is not the only trend driving Howmet's decision to invest. "Land-based industrial gas turbine components are becoming as sophisticated in their design as the most advanced aerospace components," says Larry Corliss, general manager, Hampton Casting. "Also, new designs call for larger, more complex components. We need the latest production technology to help us respond as effectively as possible to these two trends."

According to James Boutot, Howmet's IGT business manager, the designs of new land-based IGT systems are pushing technical limits to increase efficiency and durability. "The DS furnace will keep Howmet in the forefront of technical services, so we remain the preferred supplier for customers doing the most advanced developmental work," he says.

Directional solidification technology is popular with industrial gas turbine OEMs. Boutot says, "Our customers are successful selling high-technology turbines that incorporate directionally solidified castings because these systems offer the lowest life-cycle costs." Boutot adds that DS components comprised 5% of Howmet's sales to industrial gas turbine OEMs in 1990 and that sales of DS components to this market are expected to reach 26% in 1998.

Contact: Doreen Deary, Howmet Corporation, 475 Steamboat Rd., Greenwich, CT 06836-1960; tel: 203/625-8735; fax: 203/625-8796.

Howmet Invests $2.1 Million to Upgrade CVD Capabilities

Howmet Corporation's Thermatech Coating operation revealed plans during its Technology Dedication Ceremony held in Whitehall, MI, on May 13, 1998, to install a sixth chemical vapor deposition (CVD) furnace. "We installed our fifth furnace in June of last year, and it is already booked to capacity through 1998," says James R. Stanley, senior Vice President, U.S. operations. "A major capital equipment investment is a prudent response in the face of such strong customer demand. It also further underscores Howmet's commitment to provide the full range of coatings for ready-to-assemble components in all the markets we serve."

With a total of six CVD furnaces, the Thermatech Coating operation is the world's largest supplier of CVD coatings to aerospace, industrial gas turbine, marine, and other high-technology industries. As gas turbine engine manufacturers pursue better efficiencies by increasing their engines' ability to operate in higher-temperature environments, the need for protective coatings becomes a key factor in improved performance. "Protective coatings have become an integral design element, not a routine afterthought," says Cliff Sickles, general manager of Howmet Specialty Products, which includes Thermatech Coating.

Contact: Doreen Deary, Howmet Corporation, 475 Steamboat Rd., Greenwich, CT 06836-1960; tel: 203/625-8735; fax: 203/625-8796.

Nano Instruments and MTS Systems Join Forces

Nano Instruments has joined forces with MTS Systems Corporation, the Minneapolis, MN, based materials testing system manufacturer. As of 1 May 1998, the Nano Instruments Innovation Center became the new identity, but the address, phone numbers, e-mail all remain the same, as does the personnel.

Contact: MTS Systems Corporation, Nano Instruments Innovation Center, 1001 Larson Drive, Oak Ridge, TN 37830; tel: 423/481-8451; fax: 423/841-8455; e-mail: nano@nanoinst.com.

TAFA Expands Laboratory Capabilities

TAFA Inc. is expanding its laboratory capabilities with a variety of new test equipment and experienced researchers. These advancements bring TAFA's analytical, measuring, and coating improvement capabilities to a new level.

Objectives

"We are tightening the feedback loop between equipment, materials, application processes, and the resulting coating performance," says Val Zanchuk, TAFA's president. "Our goal is to ensure our technologies produce the most reliable coatings, with the highest coating performance as defined by the customer and their application. The new talent we've brought on board and our investment in new testing equipment will allow us to refine our technology development."

The objectives of the lab are to optimize:

- Processes for high production and ease of use
- Materials for purity and consistency
- Spray parameters for repeatability
- Coating performance and reliability

These objectives will be achieved through:

- Increased understanding of process-structure-property relationships
- Materials characterization
- Service simulation
- Quantification and analysis of statistical data

As TAFA expands its ability to analyze, quantify, and enhance the property relationships in coatings, these upgraded research capabilities will enable customers to apply better, more reliable coatings in more complex and diverse service environments.

Capabilities

Currently, TAFA's laboratories perform:

- High-temperature corrosion testing
- Low-temperature aqueous corrosion testing
- Oxidation testing
- Thermal shock testing
- Bend testing for metal fatigue
- Bond testing and metallographic examination

New equipment will permit:

- Pin-on-disk wear tests
- Residual stress analysis
- Thermal barrier coating tests
- Salt-spray testing
- Abrasion wear tests

Tests in TAFA's laboratories are conducted according to established ASTM or NACE standards. Where no standards exist, TAFA researchers will be developing and writing new standards for industries using thermal spray.

Technical Competence

At the head of the scientific team is Dr. Vladimir Belashchenko, TAFA's Vice-President of R&D. He has more than 20 years experience in R&D, holds 11 patents, and has authored numerous articles on thermal spray technology.

Dr. Purush Sahoo received his doctoral degree from Pennsylvania State University in Metal Science and Engineering and is the Manager of Coatings Development at TAFA. His previous research at Sermatech International Inc. focused on gas turbine component coatings.

Dr. Tetyana Shmyreva, whose doctoral degree was awarded from the Dnepropetrovsk Metallurgical Institute in 1981, assists with product development and coating characterization. She has more than 20 years of extensive, industrial research experience with all thermal spray processes in the pulp and paper industry, with the oil and gas industry, with the aircraft industry, and with many biomedical applications.

Contact: Joan Rich, Communications, TAFA Inc.; tel: 603/223-2108; fax: 603/225-4342; e-mail: info@tafa.com; web: http://www.tafa.com.

Terolab Services SA Targets Being European Leader by 2002

Newly based at the World Trade Center in Lausanne, Switzerland, TeroLab Services SA, a company formed from a management buyout on 1 June 1998 from the multinational Eutectic+Castolin Group, has just acquired the German company Bernex GmbH from the Berna Group of Olten, Switzerland. The German company specializes in the application of antiwear surface treatments. It has a staff of 100 with a turnover in 1997 of CHF 15 million. This acquisition strengthens the position of the new Swiss company on the main European market: Germany.

TeroLab Services SA, which has a license agreement with the Eutectic+Castolin Group based in St.-Sulpice, Switzerland, to use the TeroLab brand name and the related technology, comprises a factory in French-speaking Switzerland of which Mr. J.-P. Rochat is principal shareholder—TeroLab Services Switzerland in Tolochenaz (VD), as well as Terolab Services SNMC in Villeneuve-Le-Roi near Paris and in Florange in France, and now TeroLab Services Bernex GmbH in Langenfeld in Germany.

TeroLab Services SA specializes in antiwear engineered coatings and repair techniques involving a whole range of materials (metals, polymers, and ceramics). It aims to achieve the best possible results in each application, be it high-velocity thermal spraying, plasma welding, automation, or machining, to cite but a few examples. Its main customers are primarily in the energy sectors, heavy equipment, printing, automotive, biomedical, equipment manufacturing, pulp and paper, and steel industries. The company operates as an industrial contractor and covers the complete range of services from initial analysis of industrial parts to the application and the finishing of the surfacing materials. According to Christopher Wasserman, President of TeroLab Services SA, the group expects 1998 sales to be 33 million CHF. TeroLab Services SA aims by the year 2002, to become the European leader in the specific areas mentioned above. Its presence in various European countries ensures that it will be close to its customers, and this will make for optimal service: "Our ambition is to improve the quality of our services and to maintain a high level of performance in extending the useful working life of the machines and components entrusted to us by our customers, equipment manufacturers, and end users. At the same time, we wish the company to become a true partner for our customers in providing them with engineered coatings for both prevention and cure."

TeroLab Services SA's corporate strategy involves systematically seeking growth opportunities, increasing productivity by focusing on the strong points of the company's activities and expanding quality, health, safety, and environmental efforts.

Contact: Christopher Wasserman, President, TeroLab Services SA, World Trade Center; tel: +41 (0)21 641 10 85; fax: +41 (0)21 641 10 86.

News from NASA

Method for Production of Powders

Metal oxide powders are used in chemical laboratories and in manufacturing processes, but existing methods for producing them involve multistep processes requiring elaborate apparatus that are relatively time-consuming, cumbersome, and expensive. The present invention provides a technique for producing large amounts of oxide powders utilizing combustion with a minimal number of process steps. A material, which may be a metal or metal alloy, is provided in the form of a rod and put in a combustion chamber housing. An igniter is applied to it, and it is then exposed to an oxygen atmosphere, or an atmosphere enriched with oxygen. The igniter causes combustion of the material to produce powdered oxide. In one embodiment of the invention, a feeder is provided so that the material can be advanced into the combustion chamber continuously via rollers, moving through a seal so that the chamber's ability to contain the combustion reaction is preserved.

Inventors: J.M. Stoltzfus and S. Sircar, Johnson Space Center. Patent No. 5,635,153. Extracted from *NASA Tech Briefs*, June 1998.

DC-Excited Thermostrain-Gage Signal-Conditioning Circuit

Figure 1 illustrates a dc-excited Anderson-loop circuit that includes (1) thermocouples for measuring the temperature of the strain gage and (2) a signal-conditioning circuit that separates the temperature and strain-gage signals in the sense that one output voltage is proportional to the change in the strain-gage resistance and another voltage is proportional to the thermoelectric voltage indicative of the temperature of the strain gage.

The concept of the Anderson loop was discussed in three articles in *NASA Tech Briefs:* "Constant-Current Loops for Resistance-Change Measurements" (ARC-11988) in June 1998, "The Anderson Current Loop" (DRC-00001), Vol 18 (No. 12), Dec 1994, p 30, and "Patent Statement on the Anderson Current Loop" (ARC-13376), Vol 20 (No. 11), Nov 1996, p 12a. In summary: in the basic Anderson current loop, voltage drops in lead wires are excluded from measurement by use of the well-known Kelvin technique, in which a known current is supplied via two lead wires to a resistance to be determined, the voltage across this resistance is coupled to a high-input resistance voltmeter via two other lead wires, and the voltage drops in these voltage-measurement lead wires can be neglected because they carry negligible current by virtue of the high input resistance of the voltmeter.

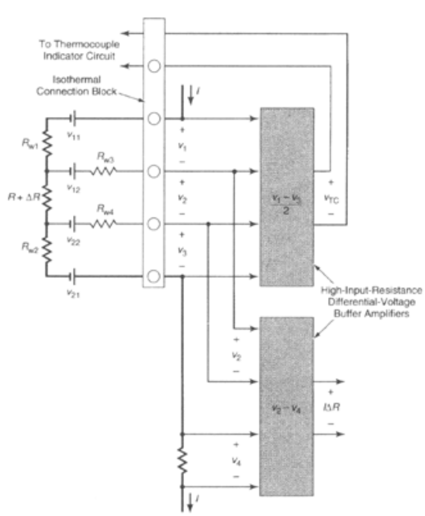


Fig. 1 Differences between terminal voltages provide indications of the temperature of the strain gage and the change in the strain-gage resistance.

Here, a known constant current I is supplied to a strain gage of resistance $R + \Delta R$ (where R is an initial value and ΔR is a change caused by the combined effects of strain and temperature). The strain-gage resistance is connected in series with two thermocouple wires of resistance R_{w1} and R_{w2}, respectively. These wires are both made of the same one of two thermocouple alloys and are of the same length, so that $R_{w1} = R_{w2}$. Two other wires (R_{w3} and R_{w4}) made of the other thermocouple alloy, are connected to the terminals for measuring the voltage drop in the strain-gage resistance. A reference resistor ($R_{ref} = R$) at a reference or ambient temperature is also connected in series with the strain-gage resistance.

The thermoelectric voltage of thermocouple (R_{w1}, R_{w3}) is given by:

$$v_{TC1} = v_{11} - v_{12}$$

the thermoelectric voltage of thermocouple (R_{w2}, R_{w4}) is given by

$$v_{TC2} = v_{21} - v_{22}$$

The thermoelectric-output-voltage level of each thermocouple represents the temperature of its connection to the strain gage.

Straightforward algebraic manipulation of the equations that relate the terminal voltages v_1 through v_4 with the voltage drops in the various resistances and with the thermoelectric voltages yields the following equations for the desired output voltages:

$$v_{TC} = (v_1 - v_3)/2$$

and

$$I\Delta R = (v_2 - v_4)$$

As indicated in Fig. 1, the terminal voltages v_1 through v_4 are coupled to Anderson subtractors comprised of buffered differential level shifting amplifiers wired to implement these equations. The subtractor outputs are then the output thermoelectric voltage v_{TC} and resistance-change voltage $I\Delta R$.

This work was done by K.F. Anderson of Analytical Services and Materials for Dryden Flight Research Center. For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Electronic components and Circuits category. Extracted from *NASA Tech Briefs,* June 1998, p 52, 54.

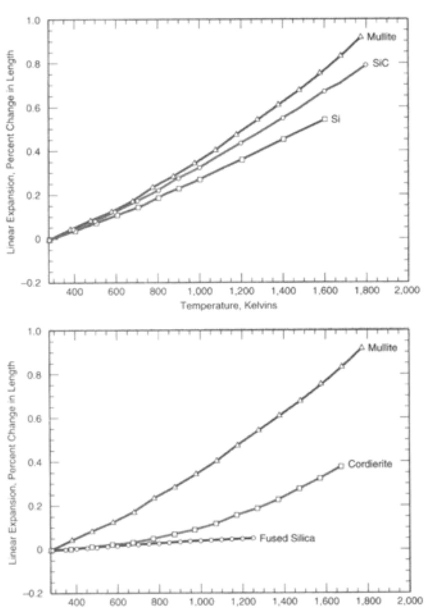


Fig. 1 Mismatches between thermal expansions of mullite and of silicon and SiC are large enough to cause cracking of mullite coatings on silicon-based substrates. Thermal expansion mismatch can be reduced by incorporating the lower thermal expansion material(s) cordierite and/or fused silica into a mullite coating.

Reducing CTE Mismatch between Coatings and Silicon-Based Ceramics

Two techniques have been proposed to reduce thermal-expansion mismatches between (a) substrates made of silicon, silicon-based ceramics, and silicon-based ceramic composite materials and (b) surface coats that protect the substrates against chemical attack in oxidizing and/or corrosive environments. Typical substrate materials include SiC/Si composites. A typical coating material is mullite ($Al_6Si_2O_{13}$), which can protect silicon-based substrates against water-free oxidizing and corrosive environments. Mullite can also be applied as intermediate coating layers to relax stresses and enhance the adhesion of overlying protective layers of zirconia (ZrO_2) or nonstoichiometric anorthite (stoichiometric composition $CaAl_2Si_2O_8$). The coefficients of thermal expansion (CTEs) of mullite and of some other typical oxide coating materials are greater than the CTEs of silicon-based substrates and, as a result, the coatings tend to crack through their thicknesses. The cracks become pathways for the entry of the chemical species from which one seeks to protect the substrates.

In one proposed technique, one or more lower-CTE phase(s) would be incorporated into a mullite coating to reduce the CTE of the coating for a better CTE match with the substrate. Suitable lower-CTE compounds include cordierite ($2MgO{\cdot}2Al_2O_3{\cdot}5SiO_2$) and fused silica (see Fig. 1). Mullite, cordierite, and fused silica would be chemically compatible with the substrate, with each other, and with typical other oxide coating materials. A composite coating of mullite with cordierite and/or fused silica could be applied by plasma spraying or by a wet chemical process.

The CTE of a polycrystalline material such as a mullite/cordierite/fused silica composite can be approximated by a rule of mixtures: $\alpha_c \approx \Sigma\alpha_i V_i$, where α_c is the CTE of the composite, α_i is the CTE of the ith constituent, and V_i is the volume fraction of the ith constituent. Initially, the proportions of cordierite and/or fused silica could be chosen to obtain a desired value of α_c, according to this rule. However, because of the complexity of the phase composition of the mullite/cordierite/fused silica system, a process of trial and error would likely be necessary to establish the optimum composition.

In the second proposed technique, zircon ($ZrSiO_4$) would be applied as an intermediate layer between a substrate and an overlying protective coating. Optionally, if a dense, crack-free zircon coating could be produced, then it could be used, instead of mullite, as a protective coating, provided that there is no water vapor in the environment. In comparison with mullite, zircon has a CTE closer to the CTEs of the typical substrate constituents SiC and silicon. If resistance to water is needed, then a protective coating of zirconia (ZrO_2) or of various silicates could be applied over the zircon layer. Zircon would be chemically compatible with both the protective coating and the thin layer of SiO_2 that typically forms on the surface of a silicon-based substrate.

Like a mullite/cordierite/fused silica composite coating, a zircon coating could be applied by plasma spraying or by a wet chemical process. Plasma spraying could be complicated by the fact that zircon melts and freezes incongruently, forming cubic zirconia first upon cooling from the liquid phase. It

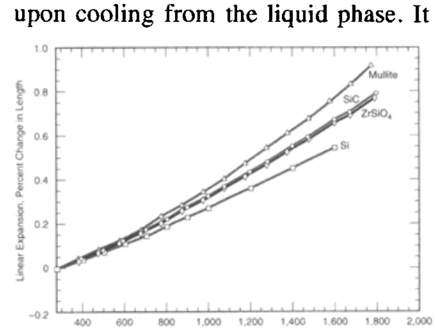


Fig. 2 The thermal expansion of zircon matches the thermal expansion of silicon and SiC more closely than does the thermal expansion of mullite.

might be necessary to add Y_2O_3 or CaO to the starting composition to stabilize the cubic phase and prevent volumetric changes while allowing the conversion to zircon to take place. Postspray annealing might be necessary to help the zircon coating reach equilibrium and enhance its stability.

The CTE of zircon is slightly less than that of SiC, though greater than that of silicon (see Fig. 2). In the case of zircon plasma sprayed on SiC, the slight difference between the CTEs results in a small compressive stress in the zircon. Inasmuch as the compressive strength of zircon exceeds its tensile strength, this small compressive stress could be advantageous in that it might offset small residual local tensile stresses and thereby help to prevent cracking. As in the first technique, one could incorporate lower-thermal-expansion phases such as cordierite and/or fused silica to obtain a lower overall CTE; for example, to obtain a greater compressive stress in a coating on an SiC substrate or to obtain a closer CTE match with a silica substrate.

This work was done by H. Wang of General Electric Company for Lewis Research Center. For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Materials category. Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16393. Extracted from *NASA Tech Briefs,* June 1998, p 66, 68

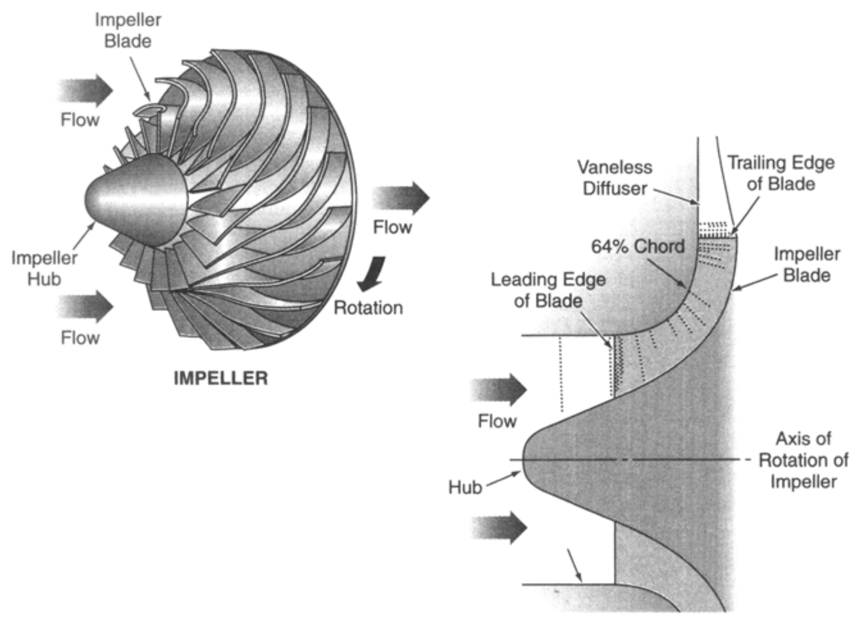


Fig. 3 Dots indicate locations, most within the passages between rotor blades, where flow velocities were measured by a laser anemometer.

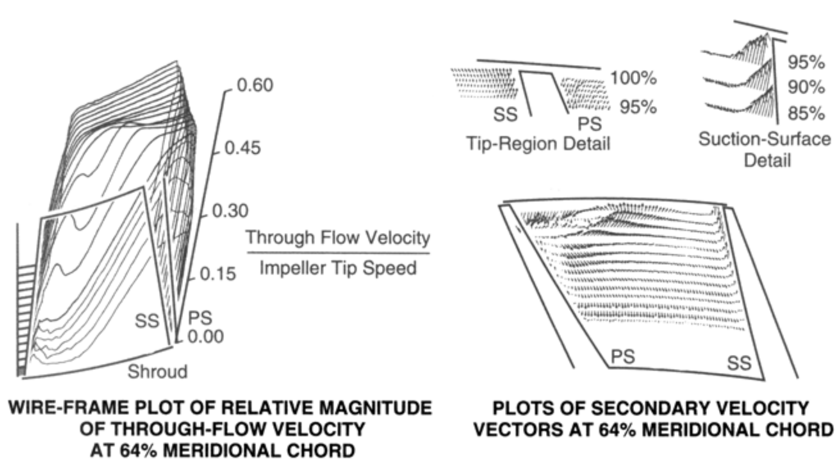


Fig. 4 Selected results of velocity measurements illustrate the general nature of the data acquired. PS and SS denote the pressure and suction surface, respectively, of a rotor blade. For clarity, different vector scales are used in the main and detail plots of velocity vectors, and the pitchwise spatial resolution of the main plot is ⅓ that of the detail plots.

Laser Anemometer Measures Flow in a Centrifugal Compressor

Detailed measurements of complex flow fields within the NASA Low Speed Centrifugal Compressor (LSCC) have been acquired. The measurement data provide insight into the fundamental physics of flow in centrifugal compressors and can be used to assess computational fluid dynamics codes and to develop flow-physics models. The resultant benefit is better predictive computational tools and shorter design cycle times.

Centrifugal compressors are widely used in auxiliary power-unit turbochargers, small gas turbine engines, gas-processing plants, and other applications. However, in comparison with their axial-flow counterparts, centrifugal compressors have generally been investigated in less detail.

The LSCC was designed to be representative of conventional high-speed subsonic compressors typically employed in small gas turbine engines. However, the measurements were acquired in the LSCC at low subsonic speeds, where the flowing air behaves as though it were essentially incompressible. As such, the measurements are reasonably representative of what would be found in many centrifugal pumps. The measurement data can therefore be used to validate any aerodynamical computer code that is applicable to centrifugal pumps.

The large size and low speed of the LSCC enable the detailed measurement, by use of a laser anemometer, of all three components of velocity within passages between rotor blades, with a spatial resolution unparalleled in investigations of high-speed compressors. For example, three-dimensional viscous flows that occur very near the surfaces of blades were measured in detail. Complementary measurements of static pressures on blade and shroud surfaces, pressure measurements by pneumatic probes at various positions across inlet and exit surfaces were acquired, and flow-visualization tracings were also acquired. Collectively, the results of the experiments in the LSCC constitute a benchmark set of high-quality data for assessing the predictive capabilities of state-of-the-art three-dimensional viscous-flow computer codes.

Figure 3 illustrates the LSCC impeller and the locations of laser-anemometer measurements. The upper part of Fig. 4 shows results of velocity measurements taken at the 64% meridional chord position, indicating the extent of the through-flow-velocity deficit characteristic of centrifugal-compressor flow fields. The lower part of Fig. 2 illustrates the nature of secondary flow measurements at the same location, along with some details that demonstrate the resolution of measurements acquired in viscous-flow regions near blade surfaces.

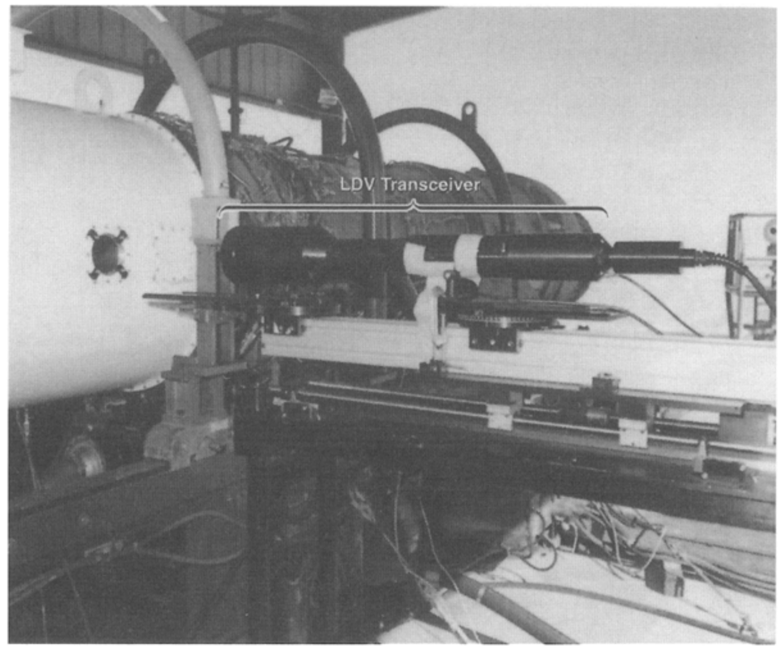
This work was done by R.M. Chriss, A.J. Strazisar, and J.R. Wood of Lewis Research Center and M.D. Hathaway of the U.S. Army Research Laboratory. For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Machinery/Automation category. Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16417. Extracted from *NASA Tech Briefs*, July 1998, p 77

Laser Doppler Velocimeter System for Use on Gas Turbines

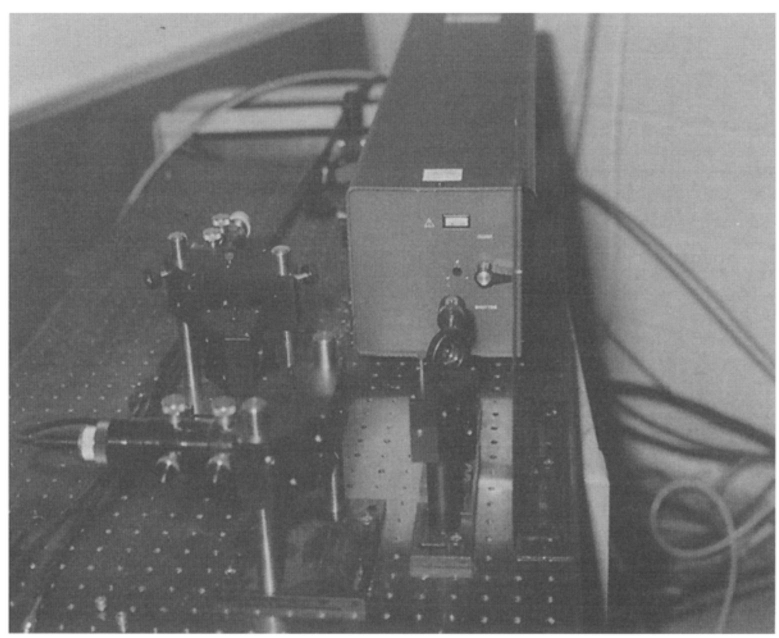
A laser Doppler velocimeter (LDV) system has been developed for use on practical gas-turbine engines. The system has been used to measure inlet and exhaust velocities on an F-100 EMD engine from an F-15 airplane (see Fig. 5). To perform this work successfully, it was necessary to develop several novel subsystems, including a rugged LDV transceiver, a high-performance frequency-domain signal processor, and equipment for adding seed particles to the inlet and exhaust flows. In addition, it was necessary to provide for remote control of the system from a blockhouse at a distance of 30 m from the engine.

The LDV transceiver features a special ruggedized design: The main structural component of the transceiver was machined from a billet of aluminum, and all optics were hard-mounted on this component. This was necessary to enable the LDV transceiver to survive the intense vibrational and acoustical fields that surround a practical gas-turbine engine.

A 40-MHz Bragg cell provides frequency shifting for the LDV. The laser beam is generated by an argon-ion laser in the blockhouse and delivered to the



LDV TRANSCEIVER MOUNTED NEAR ENGINE



LASER AND ASSOCIATED OPTICS IN BLOCKHOUSE

Fig. 5 The LDV system includes a rugged LDV transceiver mounted near the engine and connected via optical fibers to optical and electronic instrumentation in the blockhouse.

LDV transceiver by a 30-m-long, single-mode, polarization-preserving optical fiber (see Fig. 5). The intensity of the laser beam emerging from the end of the fiber-optic link in the LDV transceiver is monitored remotely, that is, from within the blockhouse. A second 30-m-long multimode optical fiber delivers the scattered light received from seed particles passing through the interferometric LDV probe volume to a photodetector in the blockhouse. This photodetector is a photomultiplier/preamplifier combination developed specially to perform at signal frequencies >120 MHz—well in excess of characteristic response frequencies of typical photodetectors in older LDV systems.

The frequency-domain signal processor, known as the "Real-Time Signal Analyzer" (RSA), was developed to provide an easy-to-operate, extremely capable processor of LDV signals. The RSA can perform up to 107 measurements per second on LDV signals and is thus capable of performing at rates well in excess of any expected data rates. Not only is the potentially noisy LDV signal measured in the frequency domain by use of discrete Fourier transforms, but the Doppler burst is also detected in the frequency domain, enabling operations at signal-to-noise ratios well below 0 dB. The output of the RSA is delivered to a laptop computer, where the results are displayed in real time and stored. All control over the RSA is exercised via this computer.

Two seeders were developed. One was an evaporation/condensation seeder that introduced a propylene glycol smoke, as a nonhazardous seeding material, into the inlet flow. This seeder was specially designed to minimize perturbation of the inlet flow and eliminate a possibility of introduction of foreign objects that could damage the engine. The other seeder—of the fluidized-bed type—introduced refractory seed particles into a moderate-pressure engine bypass airflow downstream of the engine to enable LDV measurement of the exhaust flow. Both seeders were required to provide copious amounts of seed to obtain adequate data rates at the high flow rates of a practical gas-turbine engine.

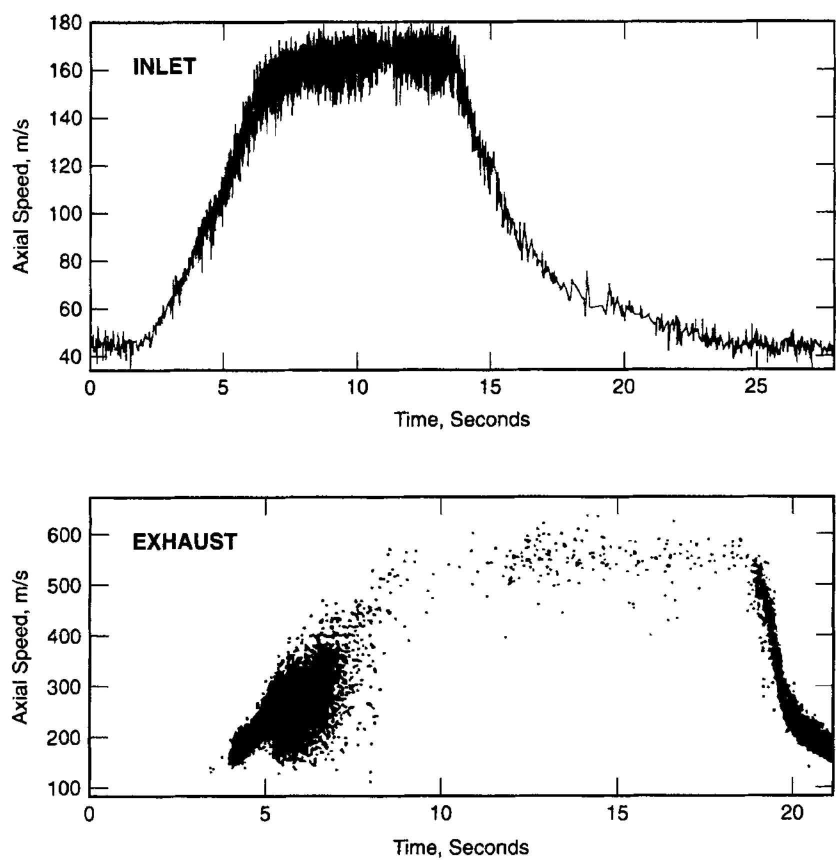


Fig. 6 Axial speeds in inlet and exhaust flows as measured by the LDV system during a transient from idle to full military power then back to idle

Figure 6 presents some results from a sample test run, showing inlet and exhaust axial speeds for a transient ramp from idle to full military power, then back to idle. The success in using this system to perform ground-based measurements raises the hope of accomplishing such measurements in flight on a practical aircraft in the future.

This work was done by K. Ennix, T. Conners, and D. Webb of Dryden Flight Research Center and R. Rudoff, J. Hanscom, R. Shearrer, and W.D. Bachalo of Aerometrics, Inc. For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Electronic Systems category. In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for the commercial use should be addressed to Aerometrics, Inc., 755 N. Mary Ave., Sunnyvale, CA 94086. Refer to DRC-98-08. Extracted from *NASA Tech Briefs,* August 1998, p 56, 58

Improved Bond-Coat Layers for Thermal Barrier Coatings

Current production thermal barrier coatings (TBCs) have been shown to be capable of reducing the average temperatures of metallic components by 50 to 80 °C and hot-spot temperature by up to 140 °C. This substantial temperature reduction has been used to extend the life of metallic components in aircraft turbines. However, for critical applications aimed at improving engine performance where significantly higher temperatures are involved, higher-durability TBCs are required. An improved bond coat incorporating metallic and cermet layers has been demonstrated to increase the thermal fatigue life of a plasma sprayed thermal barrier coating by a factor of two or more. These TBCs can be applied to components in gas turbines and in diesel engines.

A typical TBC comprises a single metallic bond-coat layer, 0.005 to 0.008 in. (about 0.13 to 0.020 mm) thick, coated with a single ceramic top-coat layer, 0.005 to 0.020 in. (about 0.13 to 0.50 mm) thick. The bond-coat layer is typically *M*CrAl*X*, where *M* signifies nickel, cobalt, or iron, and *X* signifies yttrium, zirconium, hafnium, ytterbium, or another reactive element. The ceramic top-coat layer is typically zirconia partially stabilized with 6 to 8 wt% Y. The bond coat is typically processed by plasma spraying, while the top coat can be processed by either plasma spraying or electron beam physical vapor deposition. For TBCs using a plasma sprayed top coat, the bond coat is prepared with a rough surface to improve bonding.

In spite of the necessity of bond-coat roughness to enhance adhesion, the roughness also tends to intensify the stresses that occur at the interface between the ceramic and the bond coat. Recent work has shown that the high stresses are particularly significant in the vicinity of the peaks in the rough bond coat (see Fig. 7). Detailed investigation has further shown that the stresses can be minimized by matching the thermal expansion of the peaks of the bond coat to the ceramic top coat.

Figure 8 illustrates a TBC design that addresses these problems through the use of a two-layer bond coat. The first layer of the bond coat is a typical *M*CrAl*X*, as described for a conventional TBC above. The second layer of the bond coat incorporates a fine dispersion of a particulate second phase in an *M*CrAl*X* matrix. The second phase is required to have a coefficient of thermal expansion as low as, or preferably lower than, the yttria-stabilized zirconia ceramic layer; it must be stable up to the intended use temperature, chemically inert with respect to the *M*CrAl*X* matrix,

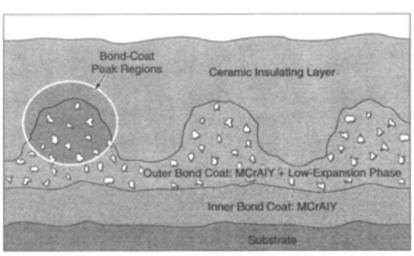


Fig. 7 Typical two-layer TBC showing the area of high stress in the peak region

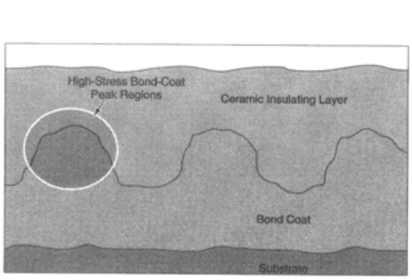


Fig. 8 Fine particles of a low thermal expansion phase well dispersed in the matrix of the second bond-coat layer, reducing or eliminating the thermal expansion mismatch with the ceramic insulating layer

and chemically compatible with the thermally grown alumina scale. Candidate second-phase materials include alumina, chromia, yttrium-aluminum garnet, nickel-aluminum spinel, yttria, mullite, and other oxides.

Because the goal is to achieve expansion matching of the second-layer peaks to the yttria-stabilized zirconia, the particulate second phase must have dimensions less than that of the peaks, typically less than 5 μm, and must be well dispersed in the *M*CrAl*X* matrix. The volume fraction of the particulate must be high enough to achieve substantial matching of the peak expansion to that of the ceramic layer. For the case of alumina additions to *M*CrAlX, an alumina volume fraction of 0.71 is required to achieve a near-zero thermal expansion mismatch. In practice, the thermal expansion of the second layer must be balanced against the other requirements for the layer, such as ductility and oxidation resistance.

Coatings to date have been plasma sprayed using starting powders produced by mechanical alloying. The mechanical-alloying process that has been developed has produced plasma spray starting powders with up to 20 vol% of a fine dispersion of submicron alumina particles. The ceramic layer life was doubled for TBCs, using a bond coat of only 5 vol% alumina additions. This technologically important, and repeatable, increase in life could be used to push the TBCs to higher operating temperatures.

Higher volume percentages of alumina, up to 20 vol%, were expected to provide even longer lives due to better expansion matching with the ceramic. While some samples did exhibit longer lives, these compositions also exhibited widely varying oxidation responses. The net result of the erratic oxidation response was a reduction in the average life for these coatings. Alternative thermal spray processes, such as high-velocity oxyfuel spraying (HVOF), have proven to produce more homogeneous particle distributions and hold the promise of even higher gains in TBC life. The HVOF coatings are currently being tested.

This work was done by W.J. Brindley and R.A. Miller of Lewis Research Center and B.J.M. Aikin of Case Western Reserve University. For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Materials category. Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16390. Extracted from *NASA Tech Briefs,* August 1998, p 64-65.

Trading Risk Versus Cost of a Composite-Material Structure

A probabilistic method has been developed for use in designing a composite material structure to achieve a balance between maximum reliability and minimum cost. This method accounts for all naturally occurring uncertainties in properties of constituent materials, fabrication variables, geometry, and loading conditions. Heretofore, it has been common practice to use safety factors (also called "knockdown factors") to reduce design loads on composite structures in the face of uncertainties. Safety factors often dictate designs of structures substantially heavier than they would otherwise be, but provide no quantifiable measures of reliability. The present method involves a quantitative approach to reliability; the equations of the method are formulated to yield a design that is optimum in the sense that it minimizes a reliability-based cost.

The derivation of the equations includes the definition of a probabilistic sensitivity that quantifies the change in reliability relative to a change in each random variable (design parameter). The probability of failure for a given performance is given by:

$$P_f = \Phi(-\beta) \qquad \text{(Eq 1)}$$

where β is a reliability index and Φ is the cumulative distribution function of a normally distributed random variable. The probabilistic sensitivity factor for the ith random variable X_i is defined by:

$$SF_i = \frac{\partial\beta}{\partial X_i} = \frac{u_i^*}{\beta} \qquad \text{(Eq 2)}$$

where u_i^* is the most probable failure point of a limit-state function in a unit normal probability space. The sensitivity of the reliability index to the mean m_i of the normally distributed random variable X_i with standard deviation σ_i is given by:

$$\frac{\partial \beta}{\partial m_i} = -\frac{SF_i}{\sigma_i} \qquad \text{(Eq 3)}$$

Similarly, the sensitivity of the reliability parameter to the standard deviation is given by:

$$\frac{\partial \beta}{\partial \sigma_i} = -\frac{SF_i u_i^*}{\sigma_i} = -\frac{(u_i^*)^2}{\beta \sigma_i} \qquad \text{(Eq 4)}$$

The reliability-based total cost function, C_T, is the criterion that enables one to achieve the balance between reliability and cost. This function is given by:

$$C_T = C_I + P_f C_F \qquad \text{(Eq 5)}$$

where C_I is the cost of manufacture and C_F is the cost incurred in event of failure of the structure. The cost of manufacture can be expressed as:

$$C_I = \sum_{j=1}^{N} C_j(p_j) + C_0 \qquad \text{(Eq 6)}$$

where p_j is a distribution parameter (which can be either m_j or σ_j), $C_j(p_j)$ is the manufacturing cost associated with the jth distribution parameter, and C_0 is a constant cost. The total cost can be minimized when:

$$\frac{\partial C_T}{\partial p_j} = 0 \qquad \text{(Eq 7)}$$

for all j from 1 to N.

Then after substitution of terms from Eq 1, 5, and 6 and use of the chain rule for derivatives, Eq 7 becomes:

$$\frac{\partial C_j(p_j)}{\partial p_j} + C_F \frac{\partial \Phi(-\beta)}{\partial \beta} \frac{\partial \beta}{\partial p_j} = 0 \qquad \text{(Eq 8)}$$

for all j from 1 to N.

For a normally distributed random variable, $\partial\beta/\partial p_j$ can be calculated by Eq 3 and 4. Equation 8 represents a system of N nonlinear equations that, if solved, yield a design with an optimum trade-off between reliability and cost.

This method can be considered a special case of method for comprehensive probabilistic assessment of composite structures. The comprehensive method is implemented in the integrated probabilistic assessment of composite structures (IPACS) computer code. [The comprehensive method was described from a slightly different perspective, with emphasis on computation of structural responses and fatigue lives, in "Probabilistic Analysis of Composite-Material Structures" (LEW-16092), *NASA Tech Briefs,* Vol 21 (No. 2), Feb 1997, p 58.]

The method was demonstrated in test case in which the objective was to minimize the reliability-based cost of a lower side panel of a composite (graphite-fiber/epoxy-matrix) fuselage structure, using, as a design parameter, the coefficient of variation (COV) of the modulus of longitudinal elasticity of the graphite fibers. For the case studied, the minimum normalized total cost for a normalized failure cost of $15,000/lb ($33,000/kg) was found to occur at COV = 0.05. The optimum COV as a function of the normalized failure cost was also computed (Fig. 9).

This work was done by C.C. Chamis of Lewis Research Center and M.C. Shiao and S.N. Singhal of NYMA, Inc. For further information, access the Technical Support Package (TSP) free on-line at www.nasatech.com under the Materials category. Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16580. Extracted from *NASA Tech Briefs,* August 1998, p 66-67

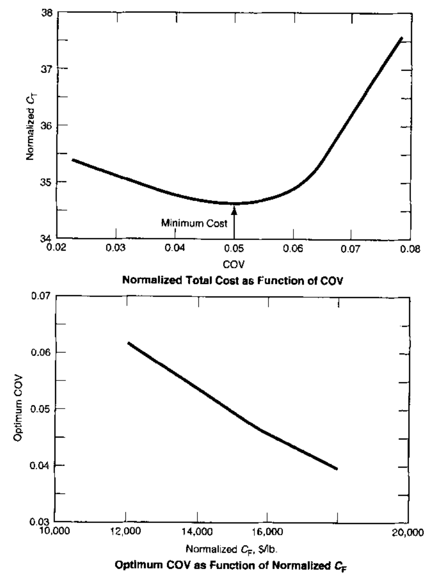


Fig. 9 Normalized total reliability-based cost (normalized C_T) in a test case was computed as a function of the COV for a normalized failure cost (normalized C_F) of $15,000/lb. The optimum value of the COV (the value for which the normalized C_T reached a minimum) was computed as a function of the normalized C_F.

U.S. Government News

Advance Could Lead Eventually to Big Savings in Metal Forming Industry

Scientists at the Commerce Department's National Institute of Standards and Technology are the first to succeed in using a new technique that shows precisely what happens to a metal when its shape is deformed. This advance is a crucial first step toward developing new computer models that could help manufacturers save hundreds of millions of dollars annually.

A single automaker alone will spend as much as $2 billion each year perfecting molds, called dies, to press sheet steel into body parts for new car models because processing steel into sheets and then pressing the metal into dies to make auto parts creates a myriad of imperfections in the atomic structure of the metal. As the sheet metal is being stamped to make auto parts, billions of unseen defects, known as dislocations, are produced that make it impossible to predict precisely how it will behave when pressed into specific dies. Current computer models do not accurately simulate what shape a die will produce. Consequently, manufacturers end up using trial and error, sometimes redesigning a die as many as 10 times before discovering the mold that forms the proper shape.

More accurate computer models would save time and money, but significant improvements cannot be made without better data about the nature of the defects. These data then require the development of a new theoretical model (also under development by the same NIST personnel) connecting the observed defect structures with the mechanical properties. The problem becomes especially bad when manufacturers try to introduce alternative materials, such as aluminum alloys and high-strength steels, whose changing properties are more difficult to predict than the standard steel presently used.

Now, 47 years after it was first proposed by a French scientist, NIST researchers have used an advanced measurement technique, known as in situ ultrasmall-angle x-ray scattering, to study the evolution of complex defect structures in deformed metals. The underlying mathematical theory was developed by Robb Thomson, Lyle Levine, and Gabrielle Long, and the corresponding experimental techniques were developed by Lyle Levine and Gabrielle Long, all members of NIST's Materials Science and Engineering Laboratory.

The NIST scientists conducted the measurements using intense x-ray beams generated at the National Synchrotron Light Source, a particle accelerator at the Brookhaven National Laboratory. They designed a special sample holder (called a tensile stage) for deforming the samples in the x-ray beam. Scientists now are able to study minute details about the formation and evolution of defects while the metal is actually being stretched and probed by the x-rays.

The next step will be to move the experiments to a new, more powerful accelerator called the Advanced Photon Source (APS) at Argonne National Laboratory. The APS produces x-ray beams 100 times more intense than the Brookhaven facility and should lead to even more accurate measurements.

For more detailed information, contact Gabrielle Long, A161 Materials Bldg., NIST, Gaithersburg, MD 20899-0001; tel: 301/975-5975; e-mail: gabrielle.long@nist.gov; or Lyle Levine; tel: 301/975-6032; e-mail: lel@argo.nist.gov.

New Products and Industry News

News from Wall Colmonoy

New Data Sheet for Colmonoy Fusewelder Torch

The Colmonoy Fusewelder Torch is described in a comprehensive data sheet, published by Wall Colmonoy Corporation. The Fusewelder Torch is a special oxyacetylene torch that can be used to protect metal parts against wear, to repair cast iron and most ferrous metals, and to restore undersized parts. The single integrated unit preheats the base metal, sprays powdered alloy, and fuses deposits to the piece.

The data sheet is concise and easy to read. Torch features are summarized. The spray capabilities of the four models are presented in a chart. The characteristics of the Fuseweld Powders are listed, including composition, hardness, and fusing temperature.

New Brochure Features Colmonoy Spraywelder

A new brochure features the Colmonoy Spraywelder. In the Sprayweld process, a Colmonoy powdered alloy is flame sprayed on a part and then the sprayed overlay is fused to the base metal by a heat source. This creates a smooth, nonporous, welded overlay.

The Spraywelder has built-in efficiency with high spray rates, tight spray patterns, dense coatings, reliability, easy operation, safety, and versatility. In addition to the base model, there is a line of accessories for more versatility.

Contact: Terry Poduska, Marketing Coordinator, 30261 Stephenson Hwy., Madison Heights, MI 48071-1650; tel: 248/585-6400, ext. 221; fax: 248/585-7960; e-mail: wcc@wallcolmonoy.com; web: www.wallcolmonoy.com.

HVOF Coating Technology Resolves Hexavalent Chrome Issues

Chrome plating companies and users of chromium-plated parts are investigating alternative processes and materials to chrome plating due to the health hazards related to handling hexavalent chromium and increasing costs incurred to meet more stringent environmental regulations.

High-velocity oxygen fuel (HVOF) systems spraying tungsten carbide or chromium carbide coatings are among the most likely candidates to replace chrome plating for a variety of reasons (see list below). The TAFA JP-5000 High-Pressure HVOF (HP/HVOF) system is particularly suited to the commercial application of these coatings due to its uniquely high production rates (up to 11 kg/h, or 25 lb/h) and optimal coating character.

- Typically, tungsten carbide applied by an HVOF coating system is five times more wear resistant than hard chrome plating as measured by a standard, dry abrasive wear test.
- Chromium plating is slow: typically, 25 μm (1 mil) thickness per hour in the tank. JP-5000 deposits 25 μm of tungsten carbide with each pass of the gun. Depending on the size of the part, the JP-5000 applies coatings faster and thicker than plating.
- Thick coatings are difficult to obtain with plating. JP-5000 applied coatings can exceed thicknesses of 50 mils (1.27 mm).
- Microcracking from residual stress in chrome plate leads to poor adhesion on iron-base materials and probable attack of the base material in corrosive environments.
- The size of the tank limits the ability of chrome plate to accommodate very large parts, but with HVOF there is no size restriction.
- HVOF coatings can be sprayed on site thereby reducing the time required to complete certain plating jobs.

An article entitled "Thermal Spray Alternatives for Electroplated Chromium," reprinted from the ASM's *Thermal Spray: Practical Solutions for Engineering Problems,* is available upon request from TAFA Inc.

Contact: Steve Griffin, Communications, TAFA Inc.; tel: 603/223-2108; fax: 603/225-4342; e-mail: info@tafa.com.web: http://www.tafa.com.

Pressure Sensors Ensure Reliability of Thermal Spray Systems

For the past thirty years, TAFA has been the premier supplier of thermal spray equipment. Thermal spraying, the process of applying a metal coating to worn-out machinery, provides manufacturers with the ability to reuse parts, thereby increasing their life span. Through this technology, TAFA has played an integral part in helping these manufacturers decrease overhead and boost profits.

TAFA uses products from Setra Systems, Inc., a designer and manufacturer of pressure and acceleration sensing devices, such as the Model 209 pressure transducer in high-velocity oxygen fuel (HVOF) combustion and plasma systems. Each thermal sprayer is unique, but for each, optimizing the performance of the process is essential. "The 209 will allow us to achieve a wide range of goals, including high performance, reliability, parts-standardization, and cost savings," states Brian Blades, manager of engineering operations at TAFA.

Contact: Setra Systems, Inc., 159 Swanson Rd., Boxborough, MA 01719-1304; tel: 508/263-1400, 800/257-3872; fax: 508/264-0292; e-mail: sales@setra.com.

Thermal Spray Data Guide Allows Easy Comparison of COFs

A new Thermal Spray Friction Data Guide, available from General Magnaplate Corporation, allows easy comparison of the coefficients of friction (COFs) of a variety of combinations of treated and untreated surfaces. The easy-to-use slide chart shows test results of standard thermal spray coatings and PLASMADIZE coatings—*The Next Generation in Thermal Sprays*—against aluminum, steel, and stainless. Also included are COFs for untreated metals against each other, as well as platings of chromium and nickel, which are mated with steel.

Both static friction (the starting friction) and kinetic friction (friction in motion) figures are shown for each combination. Use of this guide will allow engineers to select combinations of materials that can improve the service life of mating components.

Testing was standardized. The friction tester used was a T.M.I. LabMaster Slip & Friction Tester, model number 32-91-00-X. All coating specimens were finished to industry standards. Laboratory temperature was maintained at 72 °F. An average of five readings was taken for each test run.

Magnaplate-applied PLASMADIZE is a proprietary method for thermal spraying an enhanced composite matrix coatings of metals, ceramics, polymers, and/or dry lubricants. They resist corrosion and wear, are nonstick, and are FDA/USDA-compliant.

Contact: General Magnaplate Corp., 1331 Route 1, Linden, NJ 07036; tel: 800/852-3301; fax: 908/862-6110; e-mail: info@magnaplate.com; web: http://www.magnaplate.com.

A New Precoating for Solder Joining of Ceramic, Glass, and Difficult-to-Join Metals

MRi (Materials Resources International), North Wales, PA, announces the introduction of a new alloy for precoating metals, ceramics, and many other materials in preparation for soldering. The precoating material, SolderBond 500 is an active, low temperature Sn-Ag-Ti alloy that directly wets all metals, carbides, graphite, diamond, oxides, nitrides, and many composites without the use of fluxes or special atmospheres. SolderBond 500 is applied as a molten metal layer directly to the joint surfaces as a precoated or metallized layer to which any conventional solder can wet and bond. The new "active" alloy reacts with virtually any surface and produces metallurgically bonded layers. Simplicity in soldering is achieved because the new alloy precoats in air atmospheres and without flux. It is easily applied in air, at low temperatures (~500 °F), utilizing brushing, dipping, or other surfacing methods.

The SolderBond 500 process greatly simplifies ceramic and glass joining to all metals. Previously, the joining of glass and ceramic or dissimilar metals involved multiple precoating steps, including special atmospheres and vapor deposition of metal layers (gold, nickel, or palladium) or thick film premetallization techniques such as metal/ceramic frit, or the Mo-Mn process. (These thick-film metallization techniques combine oxide/metal mixtures fired at high temperatures (~950 °C), in controlled atmosphere furnaces followed by plating with a metal to prepare a solderable surface.) Importantly, MRi's new low-temperature "active" precoating alloy eliminates the need for these conventional, multistep premetallizing techniques. It is a more economic, one-step presolder coating process, followed by conventional soldering that result in joint shear strengths from 4000 to 6000 psi.

The use of SolderBond 500 has broad applications in the joining of light metals such as aluminum, titanium, and magnesium and the joining of electronic ceramic materials, as well as many other ceramic-to-metal joining applications. This new, low-temperature, active metal coating process simplifies production and lowers processing costs. Areas of application include: aerospace, automotive, heat exchangers, instrumentation, and electronics, where the alloy can be used in direct die attachment, packaging or thermal management devices. Material costs are in the range of 15 to 50 ¢/in.^{2}.

SolderBond 500 is available in wire, strip, foil, and pellets or as precoated components. Literature, application kits, and technical assistance are available from MRi.

Contact: Mike Pechulis, Materials Resources International, 403 Elm Ave., North Wales, PA, 19454; tel: 215/616-0400; fax: 215/616-0496; e-mail: solution@mri-bluebell.com.

Awards Information

AWS 1997-1998 Graduate Fellows

Each year, the American Welding Society Foundation awards graduate fellowships to students attending a welding science or engineering-related program. An award consists of $20,000, which is matched in kind by the institution of higher learning where the student is engaged in postgraduate work. The awards are renewable up to three years.

Students receiving awards for this fiscal year are:

- *Miller Electric Fellowship:* Mikal C. Balmforth, The Ohio State University, under the direction of Dr. J.C. Lippold; research project: "Development of a Ferritic-Martensitic Stainless Steel Constitution Diagram"
- *Glenn J. Gibson Fellowship:* Jack E. Helms, Louisiana State University, under the direction of Dr. Su-Seung Pang; research project: "Analysis of a Taper-Taper Adhesive-Bonded Joint"
- *Navy Joining Center Fellowship:* Todd A. Palmer, Pennsylvania State University, under the direction of Dr. Tarasankar DebRoy; research project: "Partition of Nitrogen between the Weld Metal and Its Plasma Environment"
- *Navy Joining Center Fellowship:* Daniel Hartman, Vanderbilt University, under the direction of Dr. George E. Cook; research project: "A Neural Network/Fuzzy Logic System for Weld Penetration Control"
- *AWS Fellowship:* Wesley W. Wang, Colorado School of Mines, under the direction of Dr. S. Liu; research project: "High-Performance Basic FCAW Wire Development"

AWS 1998-1999 National Scholarships

The American Welding Society is pleased to announce these recipients of a $2500 National Scholarship toward pursuing their area of study:

- *Howard E. Adkins Memorial Sponsorship:* Cory R. Reynolds, The Ohio State University
- *Edward J. Brady Scholarship:* Scott M. Tacey, Ferris State University
- *Donald F. Hastings Scholarship:* Stephen M. Levesque, The Ohio State University
- *James A. Turner, Jr. Scholarship:* David S. Hanchette, Southwest Missouri State University

AWS 1997-1998 International Scholarship

The American Welding Society award (sponsored by Praxair of Canada) to recognize superior leadership abilities in a welding student went to Nathan Nissley of LeTourneau University.

News from ITSA and ASM-TSS

ITSA's Operation Outreach

Chairman Scott Goodspeed of Praxair Thermal Spray Systems reports that Operation Outreach, a two-way information exchange between thermal spray suppliers and potential users of thermal spray, has made important inroads in new markets since the program was launched in early 1997. Central to the operation was establishing a presence outside of the traditional thermal spray conferences by maintaining information booths at such shows as AWS, NACE, TAPPI, IGTI, and others.

"The goal," says Goodspeed, "is twofold: (1) disseminate information on thermal spray to new users and learn what *their* needs are and (2) learn what specifying guidelines the thermal spray industry must adopt in order to sell to these newer markets: automobile, petrochemical, paper, biomedical, and others." In 1998, the committee is targeting a new group: a National Industrial Buyers Association, so that "purchasing agents can make informed decisions on when and how to implement thermal spray technology into their operations."

Goodspeed also noted that the ASM-TSS-ITSA Speaker's Bureau "is an important resource that new industrial users can call on to learn the methodology involved in bringing thermal spray benefits to their specific markets." In 1998, Operation Outreach will include an ITSA web site designed to bring ITSA resources to a global marketplace.

Contact: Scott Goodspeed; tel: 207/646-8669; fax: 207/646-4285; e-mail: sgoodsp@geof.psti.praxair.com.

1999 ITSA Scholarships & Awards

Chairman John Read of National Coating Technologies has announced that in 1999 ITSA will award two $1500 scholarships to graduate students with one more year of studies, and three $500 scholarships for outstanding undergraduate research papers. ITSA now awards up to three $1500 scholarships each year to graduate students from accredited institutions from throughout the world. Since 1992, ITSA scholarships have played an important part in bringing scores of talented young people into the mainstream of the thermal spray industry.

Read urges more colleges to introduce this important opportunity to students.

Contact: John Read; tel: 204/632-5585; fax: 204/694-3282; e-mail: john@nationalcccoating.com.

ASM-TSS Training Committee

Chairman Richard Knight of Drexel University reports that his committee is now working on an entry-level program for thermal spray personnel that will help shops meet the demand for more sophisticated workers in an increasingly high-tech environment, but, at the same time, meet the down-to-earth needs of the average, working thermal spray shop. "In a typical thermal spray environment, the worker must have a working knowledge of *all* the procedures involved in thermal spraying: masking, spraying, inspection," says Knight. "Our program is designed to meet these criteria."

Contact: Dr. Richard Knight; tel: 215/895-1844; fax: 215/895-2332; e-mail: knight@dunx1.ocs.drexel.edu.

Recommended Practices Committee

Chairman John Sauer of Metcut Research Associates reports that the committee is actively pursuing programs that create a forum for discussion on both a domestic and international level.

People in the News

William Zahn Named Operations Manager of General Magnaplate Wisconsin

William Zahn of Brookfield, WI, has been named Operations Manager for General Magnaplate Wisconsin, according to an announcement by Candida C. Aversenti, president of General Magnaplate Corporation, the parent company. In his new position, Zahn will have management responsibilities for production, administration, and sales in Magnaplate's upper midwest region.

For more than 30 years prior to joining Magnaplate, Zahn was employed by a large midwestern marking device manufacturer where he was Executive Vice President and General Manager.

Zahn earned his bachelor's degree in marketing from the University of Wisconsin/Milwaukee. He has been a member of the Sales & Marketing Executive's Association and was honored by the Marking Device Association International for "Outstanding Contributions to the Industry." He holds a U.S. patent for his design of a stamp rack.

Paul Zajchowski Named Pratt & Whitney Fellow

In 1997, Paul Zajchowski, a process engineer specialist with Pratt & Whitney's Development Operations Plasma Spray Coatings Group, was named P&W Fellow "for his accomplishments in the development and application of thermal spray coatings to aircraft jet engine components."

An important part of his responsibilities during his 23-year career at P&W has been to evaluate emerging coating technologies, and he has been instrumental in developing aircraft jet engine applications for HVOF tungsten carbide and chrome carbide coatings, dual wire electric arc coatings for dimensional restoration, thermal barrier coatings for diverse components, and clearance control coatings.

Today, he plays a key role in troubleshooting for P&W by providing technical assistance and conducting process reviews and training for other groups within P&W, for customers, for suppliers, and for joint ventures internationally.

As for the future, Zajchowski emphasizes that his group is constantly looking for ways to use coatings to increase the life of components, as well as for ways to reduce the cost of the coating applications process—through new programs, new materials, and new processing techniques.

In 1997, he also received the P&W/ASME "Distinguished Engineer of the Year" award.

Neal Alvanos Named National Account Manager for Ellison Surface Technologies

Neal Alvanos has been named National Account Manager for Ellison Surface Technologies, a company that specializes in the engineering and application of hypervelocity, plasma, and flame spray coatings, with plants in Kentucky and Vermont. Mr. Alvanos will be responsible for field sales throughout the United States and will manage the company's Southeastern regional sales office.

Jerry Gordon Named Vice President of Sales for Eutectic Corporation

Jerry Gordon has been named Vice President of Sales for the Eutectic Corporation. Mr. Gordon will be responsible for sales of all products, including equipment and consumables for arc welding, brazing and thermal spray, as well as the company's composite, wear plate, and safety lines. He was formerly general manager of the mid-states area for BOC Gases.

Tim Moser Named New General Manager of Praxair Thermal Spray Powders.

Tim Moser has been named the new General Manager of Praxair Thermal Spray Powders. Mr. Moser succeeds Douglas Dickerson who has retired after 34 years with the company. Mr. Moser formerly headed the Praxair Thermal Spray Systems operation in Wisconsin.

William Conley Joins Engelhard Surface Technologies as Sales Manager of Northeast Region

William Conley has joined Engelhard Surface Technologies as Sales Manager of the Northeast region. Mr. Conley, who was formerly with Sermatech, will be located at Engelhard's Wilmington, Massachusetts facility.

Klaus Dobler Joins St. Louis Metallizing

Klaus Dobler has joined St. Louis Metallizing where he will assume responsibility for thermal spray and process development. Mr. Dobler received his Masters Degree in Materials Science from the State University of New York at Stony Brook.

Benjamin Cavanaugh Joins WearMaster Inc.

Benjamin Cavanaugh has joined WearMaster Inc. as a sales engineer. WearMaster of Kennedale, Texas, is a subsidiary of St. Louis Metallizing. Mr. Cavanaugh is a graduate of LeTorneau University.

Gareth Davies Named Managing Director of TAFA Europe Ltd.

Gareth Davies has been named Managing Director of the newly-formed TAFA Europe Ltd. Mr. Gareth will be responsible for overall operation of the company. Michael Breitsameter has been named Sales Manager. Martin Flynn has been appointed Service Manager. Dr. Daming Wang will direct the research, metallurgical laboratory, and application development. Helen Sharpe and Karen Jakeman, both fluent in French and German, have been appointed to the Customer Service Team.

Discussion Topics and Threads on Thermal Spray

These questions and answers were extracted from the discussion group of the Thermal Spray Society of ASM International. The content has been edited for form and content. Note that the comments have not been reviewed. Any further discussion can be submitted to the Editor of JTST.

Question 1

Gold-Colored TS Coatings. Does anyone know of a gold-colored thermal sprayed coating that is also somewhat abrasion resistant? What about TiN? Are there any commercially available powders for TS?

Answer 1.1: Al-2Pt makes a very brilliant gold-colored thermal sprayed coating which is quite hard.

Answer 1.2: Nitrogen arc sprayed coatings are dark gold in the as-sprayed condition even before post-annealing in N_2 atmospheres. However, they exhibit the texture typical for TS coatings—much rougher than CVD or PVD. Bright gold can be obtained in the as-sprayed condition by cospraying brass and Ti using N_2-gas propellant. This pseudoalloy coating is still wear resistant and easier to machine/grind than TiN or TiN-Ni superalloy composites. I disagree that electric arc coatings are much more rough in texture than CVD or PVD coatings. We spray various alloys at greatly increased air pressure with excellent results.

Answer 1.3: It is difficult to impossible to get stoichiometric TiN by means of thermal spray. The deposited material will almost always be substoichiometric and will contain oxides and nitrides if sprayed in an ambient air environment. You will need to post treat to obtain true TiN. Titanium is also expensive and a bit difficult to work with. Although it is not as abrasion resistant as TiN, aluminum bronze has a very nice gold color, it is readily available in wire form suitable for spraying, it is easy to spray, and it is relatively inexpensive.

Question 2

Impact-Resistant Coating. I am looking for information on high impact/wear-resistant coating. Several pieces ($\frac{1}{4}$ to 1 in.) of cemented carbides are impacted at high velocity into a weld overlay protected, steel block. This weld overlay fails after ~1 month of service with the disadvantage of costly repairs and downtime. Is there a spray coating that could possibly replace our current weld overlay system?

Answer 2.1: The TSS proceeding *Thermal Spray: A United Forum for Scientific and Technological Advances,* pages 97 and 107 discusses some results regarding dry erosion at high velocity. Results in dry erosion provide the same ranking as in slurry erosion with large particles.

Question 3

Removal of TBCs. I am looking for a chemical stripping solution for NiCrAlY + YSZ two-layer plasma sprayed coating on Ni-Co-Cr-base superalloy with its application procedure.

Question 4

Dry Lubricants for Stainless Steel. I am looking for a dry lubricant for stainless steel bearings that will hold up when submerged in sulfur hydroxide in one tank and acetone in another tank.

Answer 4.1: Hexagonal boron nitride powders (HBN) are good dry lubricants with excellent resistance to corrosion. HBN may react with moisture (if present) under extreme pressures or at high temperature; however, the by-products increase lubricity.

Answer 4.2: There is a process called "kolsterizing" which was developed specifically for austenitic stainless steel which achieves a hardness of 1100 HV, thereby improving greatly the sliding characteristics without affecting corrosion resistance.

Question 5

Thermal Spraying of Alumina.

Does anyone have information on the thermal spray deposition of alumina in densities high enough to result in translucency. How densely can one expect to deposit alumina? Can one spray form free-standing translucent alumina in thickness between 1 and 2 mm?

Question 6

Disposal of TS Waste. I would like to discuss thermal spray waste disposal. My company uses two methods of collecting overspray from the thermal spraying process: wet collectors and dry dust collectors. Currently, we dispose of the waste sludge and dry powders in a landfill. I have tried to find alternative ways of disposing of this waste but have not had much success. The majority of people I have contacted are not familiar with this type of waste. For instance, many contacts keep trying to classify my TS industry as *powder paint coating waste* or as *plating waste.* We have had mixed results with the local and state pollution control agencies as well as our waste hauler as to alternatives to a landfill for the same reason: lack of familiarity. Is the landfill the only way to dispose of this waste, or are there recycling methods that can extract the various metals which they can resell? What do other companies do with their waste?

Answer 6.1: Although we use our reactor to manufacture powders, we would be interested to investigate its application to metal recovery from overspray/scrap powder. In short, we conduct CVD/PVD onto the surface of metal and ceramic powders to create alloys and composites (e.g., WC-Co, NiAl, high-nitrogen SS powder), or to purify powders. The reactor is a combination of fluidized bed and vacuum furnace technologies, supporting a broad range of process conditions (vacuum to multibar pressure, temp to 1050 °C, controlled atmosphere). In one case, we have some experience with processing boron chemicals in a chlorine atmosphere at high temperature (the objective is to boronize parts using Cl as an "activator"). If the kinetics are reasonable, we may be able to convert metal and some oxide powders to single-metal halides (chloride, iodide) which could be further refined or separated, then reacted to yield the elemental powder(s) and recyclable halide. I doubt that, in and of itself, this is a cost-competitive powder production method. However, it may be a cheaper disposal option (after sale of the refined material) and eliminates the disposer's liability if the dump ends up under a cleanup order.

Answer 6.2: Thermal spray waste is recyclable like any other metallic waste. The first step in finding a recycling plant is to have the waste chemically analyzed for content. The waste must be dry, and you may also have to recycle your other waste (wires, powders, etc.) with the same recycling agent to provide some incentive.

Question 7

Influence of Feed Rate on Coating Properties. I would be interested to hear from anybody who has done any research into the effect of wire feed rate on the resultant coating; i.e., integrity, thickness, particle size, catch rate, etc., with regard to the flame spray process. Also, has anybody devised a way of characterizing the flame parameters, or is it assumed that controlling gas flows is sufficient? Does anybody have any data on the benefits of spraying with nitrogen as an atomizing medium as opposed to air?

Answer 7.1: A few comments. (1) Arc spraying is a faster, less expensive process that produces better coatings. (2) When arc spraying you would produce somewhat more conductive, more sticking, and less defective coatings using nitrogen instead of compressed air. However, electric conductivity of Al coatings is primarily a function of coating thickness. Also, in the case of nonmetallic substrates, nitrogen spraying is superior for a significantly lower deposit temperature, which leads to much less damage of the interface and a better adhesion. (3) Similar to the atomization of metal powders, wire spraying, flame or arc, produces finer or coarser droplets and, consequently, coatings (smooth and dense vs. rough and porous, respectively) depending on the gas-to-metal mass ratio. Thus, if you increase wire feed rate your coatings will be rougher and, possibly, more porous. However, increasing flow rates of oxidizing gases will also increase the degree of coating oxidation.

Answer 7.2: Our metal spray gun is a standard product, although the application is unique to us. The material I am spraying is predominantly copper alloyed with other materials to increase the resistivity. Our coatings are sprayed to an overall resistance which gives a resultant coating thickness of 0.003 to 0.004 in. The substrate is a glass fiber composite with a high-temperature epoxy resin system.

Answer 7.3: Some years ago, we developed erosion-resistant antilightning coatings for C-C composite boards/wings. In the basic version, a 0.002 to 0.003 in. thick bond coat of the traditional eutectic Al-Si (~12% Si) was oversprayed with a 0.006" thick Ti-AlSi pseudoalloy layer using one Ti-feedwire and another AlSi feedwire. Since these coatings were (air-environment) arc-sprayed using pure nitrogen, the bottom layer didn't "burn" the composite while the top layer contained a fraction of hard (1800 HV), gold-colored TiN_x particles. An erosive jet of angular alumina particles was used to measure erosion resistance of the coating. There are a number of combinations one may use to control properties of coatings when two different feedwires are sprayed. Examples: Al-Zn, or AlMg-Zn, where Zn acts almost like an "in situ" sealer, can be sprayed directly on Lexan or similar polycarbonate materials, not to mention real epoxy composite substrates for aerospace.

Question 8

Experience in Using Different Flame Spraying Guns. Is it typical for the wire feed rate to be fed back to the motor speed controller and therefore the motor speed is adjusted relative to the wire speed, or use a motor speed tachometer feeding back to the motor speed controller, which therefore controls the motor speed, possibly independent of the wire speed and have a separate system monitoring the wire speed?

Question 9

TS for Zinc Pot Rolls. I have read several articles on the application of thermal spray coatings on zinc pot rolls. Because of the commercial value of the technology, these articles however often hide more than what they reveal, and the "successful" applications are merely hinted at. The bearings of these pot rolls are also a major problem—has anybody explored the application of thermal spray coatings in this application?

Question 10

Rain Erosion Coating

Does anybody have a metal sprayed rain erosion coating to offer? If not, is this an application that is practical for a metal sprayed coating applied to a component under thermal and dynamic stress?

Question 11

De-Icing Components. The company I work for produces aerospace components; the area I support is Ice Protection Systems. The components we de-ice are leading edges of helicopter rotor blades, engine intakes, etc. We currently have erosion coatings applied by paint spraying, but we are always looking for improved materials and I suspect that there are suitable metal sprayed coatings out there.

Answer 11.1: Have you considered thermal spraying a plastic for such applications? Previous testing on elastomers and low-melting-point plastics show excellent cavitation-erosion and solid-particle erosion results. However, there are temperature restrictions with these resins and higher-melting-point plastics may not be suitable for leading-edge applications if they are too brittle.

Question 12

Mo-Base Feedstock. I want to purchase "preoxidized Mo powder" for experiments of wear-resistant coating.

Answer 12.1: People have used arc sprayed Mo wires using compressed air. This is much less expensive and faster than plasma and high quality. A conventional plasma could also be used to feed "metallic" Mo powder using air or oxygen-enriched air as the powder carrier gas.

Question 13

Safety Issue for Hydrogen. Could technical grade hydrogen be odorized? Forced ventilation is a good way to keep concentration below the inflammation limit, but it would help if we could smell hydrogen.

Answer 13.1: Odorizing hydrogen gas would normally be a good idea. The problem is that hydrogen reacts easily with virtually everything.

Answer 13.2: I have installed several thermal spray cells with gas sensor systems. Considering the weight of hydrogen, these sensors were installed on the ceilings. For propylene, which is heavier than air, I have installed these sensors on the walls, 6 in. above the floor. Additionally, sensors were installed at the compressed gas sources. It is also possible to leak check all fuel gas and oxygen lines. Furthermore, the frequency of tests for all sensors and fittings should be employed and recorded. All fuel gas sensors are further tied into red beacon lights and audible alarms, which are activated when gas presence is greater than 20% of the lower explosive limit.

Question 14

Safety Issues for Thermal Spray. I need information regarding personnel safety and environment protection regulations for the thermal spray process for the European market.

Answer 14.1: There are some safety and environmental aspects for thermal spraying (especially for Germany) that take care of some of these issues. There are so far no general worldwide rules for thermal spraying, because environmental regulations depend on national laws. In Germany there is, for example, the SLV Munich that offers different training courses—even ending with a European certificate as European Thermal Sprayer-Practitioner, or -Specialist. Here are some DVS recommendations and European/International standards:

1. DVS 2304—Gütesicherung beim thermischen Spritzen
2. DVS 2306—Lehrgänge; Thermisches Spritzen
3. DVS 2306-1—Grundlehrgang für Flamm- und Lichtbogenspritzer/Basic training course for flame and arc sprayers
4. DVS 2306-2—Aufbaulehrgang für Flammspritzer/Advanced training course for flame sprayers
5. DVS 2306-4—Lehrgang für Pulverspritzer/Training course for powder sprayers
6. DVS 2306-5—Lehrgang für Aufsichtspersonen für das thermische Spritzen/Training course for supervisors for thermal spraying
7. DVS 2306 Beiblatt—Prüfung von Pulverspritzern/Examination of powder sprayers
8. DVS 2306 Beiblatt 1—Prüfung von Flamm- und Lichtbogenspritzern/Examination of flame and arc sprayers
9. DVS 2306 Blatt 3—Aufbaulehrgang für Lichtbogenspritzer/Advanced training course for arc sprayers
10. DVS 2307-1—Arbeitsschutz beim Entfetten und Strahlen von Oberflächen zum thermischen Spritzen/Industrial safety in degreasing and abrasive blasting of surfaces for thermal spraying
11. DVS 2307-2—Arbeitsschutz beim Flammpritzen
12. DVS 2307-3—Arbeitsschutz beim Lichtbogenspritzen
13. DVS 2307-4—Arbeitsschutz beim Plasmaspritzen
14. DIN EN 481—Arbeitsplatzatmosphäre; Festlegung der Teilchengrössenverteilung zur Messung luftgetragener Partikel; Deutsche Fassung EN 481:1993/Workplaces atmospheres; size fraction definitions for measurement of airborne particles; German version EN 481:1993/Atmospheres des lieux de travail; definitions des fractions de taille pour le mesurage des particules en suspension dans l'air; version allemande EN 481:1993
15. EN 481—Arbeitsplatzatmosphäre; Festlegung der Teilchengrössenverteilung zur Messung luftgetragener Partikel/Workplace atmospheres; size fraction definitions for measurement of airborne particles/Atmosphers des lieux de travail; definition des fractions de taille pour le mesurage des particules en suspension dans l'air Intern.
16. GUV 9.10—Unfallverhütungsvorschrift "Verarbeiten von Beschichtungsstoffen" mit Durchführungsanweisungen
17. ISO 7708—Luftbeschaffenheit—Festleg ung von Partikelgrössenverteilungen für die gesundheitsbezogene Schwebstaubprobenahme/Air quality—Particle size fraction definitions for health-related sampling/Qualite de l'air - Definitions des fractions de taille des particules pour l'echantillonnage lie aux problemes de sante
18. prEN 1093-1—Sicherheit von Maschinen; Bewertung der Emission luftgetragener Gefahrstoffe; Teil 1: Auswahl der Prüfverfahren / Referenz: 89/392/EWG/Safety of machinery; evaluation of the emission of airborne hazardous substances; part 1: selection of test methods/Securite des machines; evaluation de l'emission de substances dangereuses vehiculees par l'air; partie 1: choix des methodes d'essai

19. prEN ISO 14918—Thermal Spraying: Approval testing of thermal sprayers

This gives at least some input, but much world wide effort is needed for thermal spraying to become a clean and environmentally friendly technology (including overspray/waste treatment)!

Question 15

Internal Diameter Spraying. I am considering to spray and then fuse the internal diameter of steel tubes with lengths between 1 and 2 m and diameters from 50 to 100 mm. I do not want to consider plasma but prefer oxyacetylene spraying. Is there any information concerning such a process?

Question 16

Thickness Uniformity of Coatings. I am trying to establish the thickness uniformity of a flame sprayed copper alloy coating, with the objective of establishing the uniformity of the metal spray gun coating delivery. Can anybody recommend a suitable substrate material which, if sprayed uniformly, will catch the metal spray uniformly. The substrate must be an electrical insulator in order for me to conduct the thickness tests.

Answer 16.1: You can spray metallic materials onto a nonmetallic substrate such as glass. Be aware that the spray deposit contains oxides which can affect the measurement. You will probably have to modify the attenuation and calibrate the thickness tester.

Question 17

Arc Spraying of Copper Alloys. I would be interested to receive information regarding arc spraying of copper alloys. All of our spraying is with flame spray guns which deliver a fine coating. A concern with arc spraying is that the deposition rate is too high for the intended application which is an epoxy composite substrate.

Answer 17.1: Spray rate is not a concern since this can be down to five lb/h. Typically, the advantages of arc spraying over flame spraying will include higher bond strength, coating consistency and ease of automation.

Question 18

Temperature Reduction. We are looking to reduce surface temperature of either copper, brass, or stainless steel from 400 °C down to 65 °C. Can anyone recommend any system and products for this task?

Answer 18.1: If you assume a 100 °C temperature gradient from the surface of a nominal 10 mil thick partially stabilized zirconia, to the substrate, you could apply a 32 mil coating to achieve temperature reduction. The temperature/coating thickness curve, at higher temperatures, will plateau.

Question 19

Color Changes in Hydroxyapatite. I am now using hydroxyapatite powder. I found that when I sinter the powder at 1350 °C, it turns blue. Is there any suggested reason for the blue color? I have checked the x-ray diffraction pattern of this powder with JCPDF Card 9-432; the starting powder is found to be well-crystalline pure hydroxyapatite and there was no second phase found from room to 1350 °C.

Answer 19.1: I was told that this color change was due to trace amounts of iron. I have another colored hydroxyapatite effect - black HAp. This happens occasionally, in "reducing" conditions and at around 1000 °C. Anyone know why this occurs?

Answer 19.2: Following is a summary of the information as has been posted by Dr. Karlis Gross, an article directly related to the blue color is:

- L. Yubao, C.P. Klein, X. Zhang, and K. de Groot, Relationship between Colour Change of Hydroxyapatite and the Trace Element Manganese, *Biomaterials,* Vol 14 (No. 13), 1993, p 969-972

Other articles related to Plasma HAp powder are:

- A.J. Ruys, M. Wei, C.C. Sorrell, M.R. Dickson, A. Brandwood, and B.K. Milthorpe, "Sintering Effects on the Strength of Hydroxyapatite," *Biomaterials,* Vol 16 (No. 5), 1995, p 409-415
- A.J. Ruys, A. Brandwood, B.K. Milthorpe, M.R. Dickson, K.A. Zeigler, and C.C. Sorrell, "The Effects of Sintering Atmosphere on the Chemical Compatibility of Hydroxyapatite and Particulate Additives at 1200 °C," *J. Mater. Sci. Mater. Med.,* Vol 6 (No. 5), 1995, p 297-301
- A.J. Ruys, C.C. Sorrell, A. Brandwood, and B.K. Milthorpe, "Hydroxyapatite Sintering Characteristics: Correlation with Powder Morphology by High-Resolution Microscopy," *J. Mater. Sci. Lett.,* Vol 14 (No. 10), 1995, p 744-747
- A.J. Ruys, K.A. Zeigler, O.C. Standard, A. Brandwood, B.K. Milthorpe, and C.C. Sorrell, "Hydroxyapatite Sintering Phenomena: Densification and Dehydration Behaviour," *Ceramics: Adding the Value,* Vol 2, M.J. Bannister, Ed., CSIRO Publications, Melbourne, 1992, p 605-610

Answer 19.3: If the color change is caused by the trace amount of the impurities in the powder, do these impurities cause any biological effect? ASTM standard F 1185-88 of HAp for surgical implants has a concentration limit for As, Cd, Hg, and Pb in the ppm range. How about those other impurities, like manganese, magnesium, and iron? Do we have to worry about them? Or do we justify that they are relatively harmless by in vitro and in vivo study?

2) Related to Plasma Biotal HAp powder, is there any in vivo or in vitro study done using these powders?

3) As pointed out by the responses from the list, when I sinter this Biotal HAp powder at 1350 C in air, I will be getting oxyhydroxyapatite. My IR result indeed confirmed that. My question is about this oxyhydroxyapatite. Both of the articles I have about oxyhydroxyapatite are in vitro studies, "The Effect of Calcium Phosphate Ceramic Composition and Structure on in vitro Behavior. I. Dissolution," P. Ducheyne, S. Radin, and L. King, *J. Biomed. Mater. Res.,* Vol 27, 1993, p 25-34; "The Effect of Calcium Phosphate Ceramic Composition and Structure on in vitro Behavior. II. Precipitation," S. Radin and P. Ducheyne, *J. Biomed. Mater. Res.,* Vol 27, 1993, p 35-45. My question is: Has the in vivo behavior of oxyhydroxyapatite been investigated?

Question 20

Materials for Tank Floors. I am looking for information on spray types or materials that may be applied on a tank floor that is subject to high pH.

Question 21

Safety—Breathing Apparatus. I have a question regarding breathing apparatus and/or filters for operators of plasma systems. What air quality safety equipment is being used in the field for plasma system operators? I could use feedback on the pros and cons (i.e., field reports) of the various breathing equipment options along with information as to who the equipment manufacturers and/or distributors of the equipment are. We are going to update our equipment, and we are interested in equipment that have the following specifications: a face mask, a dark lens suitable for a plasma flame, a clear lens suitable for reading console gages, free movement of operator, and integral respirator and/or filters.

Question 22

Impact Tests for Coatings. There are many informal impact tests involving ball peen hammers, dropping shafts on cement floors, etc. What are the technically most suitable, quantifiable impact tests for coatings such as WC-Co, cermets, and ceramics?

Answer 22.1: Low-velocity impact tests were conducted on plasma sprayed coatings on an aluminum substrate as described in the article by R.D. Seals, C.J. Swindeman, and R.L. White, "Thermal Spray Deposition and Evaluation of Low-Z Coatings," *Proc. Ninth National Thermal Spray Conference,* C.C. Berndt, Ed., 7-11 Oct 1996, p 13-19. We searched the ASTM Standards before the outset of impact testing our specimens. I don't remember finding anything. The impact test we conducted with a falling spherical mass is used in testing of composite plates. The falling spherical impact test has significant advantages in that the center of gravity for the impacter is always in line with the velocity vector. This would never be the case with a falling wrench, hammer or rod—no two tests would be the same. Quantitatively speaking, the falling spherical mass is easily handled. Newton's laws apply for displacement, velocity, acceleration, force, work, and kinetic and potential energy. The Hertzian forces at the impact site have been determined by previous investigators.

Answer 22.2: A ball peen hammer is an excellent tool for comparative tests and will eventually even allow for some approximate quantitative results, if you have a standard for comparison. It's inexpensive and fast, but destructive. Perhaps anybody involved in thermal spraying should apply a few typical coatings with different equipment and destroy them with a file and hammer. The file test should be done both with light pressure to feel microhardness and high pressure, to feel when particles start to pull out. It is also amazing, how easily some coatings pop off and how resistant others are to repeated blows of a peen hammer. However important I think these tests are to get a feeling; they might be a long way from qualification as sales engineer!

Question 23

What is the best type of powder feeder (physical mechanism and/or specific supplier model number) for feeding fine (1 to 10 μm) zirconia or yttria powder for plasma spraying? Are there any specific precautions for powder line configuration, rate of powder feed, powder handling, preheating, etc.? What is the smallest powder lot that can be sprayed using the appropriate precautions?

Answer 22.1: For 1 to 2 μm tungsten powder I used an ultrasonic device and a feed tube which was 0.125 inside diameter and made of polyethylene. This improved the feed rate from roughly 10 g/min to more than 100 g/min. The ultrasonic device worked best.

Question 23

Surface Temperatures for Thermal Spray Processes. I would welcome any information regarding expected surface temperatures when using different spraying methods, i.e., flame, arc, HVOF, etc. Is it possible to maintain surface temperatures below 100 °C for all processes? Does the material being sprayed make any significant difference? Does the selection of gases make any significant difference?

Answer 23.1: Thermal spray technology has various processes, all of these are so-called cold spray processes where the surface temperature will be kept low (with or without the use of cooling). A common rule is to keep the surface temperature below 150 °C. Only one technique will require a surface heating up to ~1000 to 1200 °C; i.e., for fusing the coating with the substrate; the so-called "fused coatings." The latter is commonly interpreted as being a coating sprayed by means of flame powder (sometimes HVOF) after which the coating is fused. Sometimes the sprayed material is fused with the substrate simultaneously. The different spray process all have their own "regular" temperatures. An approximate ranking (from cold to "hot") is: arc, flame wire (nonfusing), flame powder, HVOF, and plasma. Arc spray is seen as the coldest process; it is used for spraying zinc on capacitors and varistors as well as on the inside of computer monitor housing (for EMI/RFI shielding). The maximum temperature of 100 °C can be obtained by cooling the part and spraying thin layers per pass.

Question 24

Training Courses for Thermal Spray. I am learning to spray, and I am looking for any information that someone can give me so that I can have a better understanding of what I am doing.

Answer 24.1: ASM International has a correspondence course in Thermal Spray Technology that is very good. It covers Surface Science, Equipment and Theory, Testing, and Characterization, Selected Applications, Processing and Design, Materials Production for Thermal Spray Processes.

Answer 24.2: The Thermal Spray Society of ASM International has a variety of educational/training courses and materials that may be very useful to you. Please send your full address to Ms. K.M. Dusa, ASM International, by e-mail at KMDusa@po.asm-intl.org, and I am sure she will be happy to send you the information. I believe you would also find it very useful to become a member of the ASM Thermal Spray Society, which includes membership in ASM International. This will help you to keep up with new developments in equipment, materials, and applications, not only in thermal spray, but in other all fields of materials. Finally, I strongly suggest you subscribe to the *Journal of Thermal Spray Technology* for a more in-depth understanding of the field presented in a very readable manner and for a very reasonable price. If you can arrange to do so, attending the United Thermal Spray Conference and Exhibition to be held next year in Düsseldorf, Germany and cosponsored by DVS and ASM TSS would give you an opportunity to see the latest thermal spray equipment, attend excellent technical sessions, and talk to experts in the field.

Question 25

Coatings for Compressor Exhausts. Is there a consensus for the most cost-effective thermal spray coating for high-temperature (1000 to 1500 °F) nominally industrial environment? The specific application is for 36 in. compressor exhausts which can reach near the upper end of that range.

Answer 25.1: I think that you will find the consensus will be Chromium Carbide, probably the 75 CrC 25 NiCr. It is relatively inexpensive, compared to many alternatives and is widely used in exhaust gas applications. It has good resistance to particle erosion and high-temperature corrosion. It has good thermal shock resistance and a coefficient of thermal expansion which allows it to undergo many cycles without cracking or spalling. It can be applied in adequate thickness for the application. It is best applied by HVOF, in my opinion, but it has been applied for years in turbine environments by plasma spray.

Answer 25.2: Arc sprayed aluminum coating has been used successfully in many similar applications.

Question 26

Bond Strength Testing. We are discussing tensile bond strength testing for various thermal spray coatings. As a rule, we currently standard 1 in. round bond bars with a minimum shank beyond the threads of 1 in. pulled by a tensile testing device. I noted several papers showing that this standard had been upgraded to a minimum of 2 in. minimum shank beyond the threads. Others that indicate that this test may need to be totally rethought. What is the current thinking for bond strength testing for thermal spray coatings? A key factor is that the technique needs to be fairly universal (if possible), and applicable to TBCs, hardface, bond coat materials, and abradable coatings.

Question 27

Nitrogen as a Primary Arc Gas. I am reviewing the potential of allowing nitrogen as a primary arc gas for application to a wide range of thermal spray coatings (mostly plasma). Primary customer concerns include nitriding of the base metal and embrittlement of the bond coat/final coating. Are there any comments?

Answer 27.1: The basic spray parameters would need to be redeveloped since, taking the case of plasma, you will change the arc voltage (hence kW) and enthalpy of the jet. Heat transfer to particles will also change. Use of nitrogen will also shorten electrode lifetime, and if you're operating under atmospheric conditions (APS) more NO_x will be produced.

Question 28

Hard Chrome Replacement. I would like to propose using thermal spray in place of chrome plating for wear and corrosion resistance in Navy valves and shafts. Unfortunately, I can find little documentation that this process is superior to chroming. Can you provide or point me to any documentation of the impact of thermal spray on maintenance periods or corrosion resistance etc.?

Answer 28.1: The proceedings from ITSC 98 (Nice) include a paper by Lufthansa on the subject (p 1073, HVOF Spraying vs. Hard Chrome Plating Aircraft Applications) that you might find interesting. Another consideration is the reduced environmental impact using thermal spray.

Answer 28.2: You might try searching the indices of the annual ASM thermal spray conference proceedings (NTSC, ITSC, UTSC). All of the proceedings since roughly 1990 have a topical index, and you can also electronically search the table of contents of the *Journal of Thermal Spray Technology* on-line at http://www.asm-intl.org/tss/index.htm.

Question 29

Sparking Risk for Thermal Spray. It has been suggested that thermal spray on live petroleum platforms is not allowed as there is a sparking risk. Can anyone verify this?

Answer 29.1: A mixture of surfaces which are TS coated and especially corroded iron surfaces can cause sparking if knocked together. The result is a small thermit reaction. One of the ways around this problem is to coat the iron surfaces either with Al or bronze to create nonsparking surfaces. Indeed one application of TS is to coat equipment such as oxygen bottles used offshore.

Answer 29.2: The use of TS on offshore rigs and platforms is kept to a minimum as it is safer, and maybe commercially better, to weld anodes to the structure and complete the corrosion protection system with paint. Where TS is used it is generally restricted to open, well-ventilated areas, such as flare stacks. I did hear that when constructing the English Channel Tunnel, no TS was allowed inside the tunnel, whereas it was OK for external structures. It would seem that designers and constructers apply a safety-first policy where there is a risk of fire.

Answer 29.3: You may wish to check the Australian Navy metallizing specifications on the issue of aluminum and sparking. They use flame sprayed zinc overcoated with flame sprayed aluminum in many areas. One exception to this is in ammunition magazines aboard ship where TS zinc only is used to avoid sparking.

A second TS reference is to the governing agency for British mines. Pure zinc and zinc-15 aluminum are allowed to be sprayed for mine applications where methane or other gas may accumulate. Their regulation says a maximum aluminum of about 15% may be used.

Answer 29.4: In recent years, tens of thousands of square meters of live offshore oil and gas production platforms have been sprayed for the U.K. Norwegian North Sea market. This is not just flare booms and bits and pieces, but whole jackets, cellar decks, steam piping, helidecks, etc. as well as flare booms, and also land-based installations.

Answer 29.5: I had the impression that two different kinds of sparking have been discussed. The first is the use of any welding or TS equipment on platforms. The place is not different in that respect from any refinery. If you have explosive mixtures of air and combustible gases, a spark will cause an explosion. The proportion of air to gases is, fortunately, quite critical. In closed tanks or tubes you will experience problems, but people working with any kind of petroleum compound are normally well trained and observe safety instructions. Most people's noses are perfect indicators. If you don't have a cold and can't smell petroleum compounds, then usually there is no dangerous concentration. Don't rely on this, however.

The other kind of sparking is caused by friction. A steel hammer thrown or falling on steel may cause a spark just like grinding. Thermite reactions require a threshold temperature of about 8000 °C.

Since aluminum is a soft material, I don't think an accidental reaction of iron oxide by aluminum is possible. Energy will be absorbed by progressive deformation of aluminum and steel, just like modern car bodies.

Question 30

Critical Variables to Reduce Oxidation and Porosity. Upon applying a TS coating to a part, metallurgical analyses are done to check the interface, as well as the oxidation and porosity of the coating. In many cases, industries see that there are problems/failures in their processes, but are not so sure as to why such failures occur. I would like to know which variables are the most critical when trying to reduce TS coating oxidation and porosity.

Answer 30.1: I would say that the biggest factor, in general, would first and foremost be process selection. VPS for example should produce coatings with lower oxidation and similar or maybe higher density than the same material sprayed by APS or HVOF (assuming of course that the material in question can in fact be sprayed by several processes). Other than that it comes down then to jet enthalpy (which is affected by different parameter combinations from process to process—power input and gas composition in plasma; fuel:oxygen ratio in HVOF, etc.), spray distance (i.e., particle dwell time in the jet), and substrate temperature.

Answer 30.2: I have found in my own experiments that the correct carrier gas injection is either the first or second most important variable. Not enough carrier gas and the powder will not melt sufficiently, producing a porous coating. Too much and the powder will shoot through the plasma; this has been shown to make coatings with excessive oxidation. Some people have their preferences, but I prefer to have the powder injected right down the middle of the plasma jet. This method also makes it simpler to align your gun to the part.

Answer 30.3: I'd also like to emphasize the usefulness of a simple "wipe test" when dealing with a new system/material. This means to move quickly, in a windshield wiperlike fashion, a thin glass slide (about 100 by 20 by 2 mm) through the powder-loaded plasma jet to catch individual droplets. Under an optical microscope/stereomicroscope at low magnification (or SEM for higher resolution) the degree of melting/splashing of the droplets can be easily evaluated. From such data it can be decided whether the spray parameters used are way off or close to optimum.

Question 31

TS for Hydroxide Environments. Has there been any successful experience with a TS coating against NaOH at 15% concentration, 8 to 9 ph and 120 °C?

Answer 31.1: Just about any nickel or Ni alloy coating will resist pH 8 to 9. Choose according to abrasion. If there is no wear, no chlorides, and pH really never gets above 8 to 9, then aluminum should be serviceable. No through pores are allowed, and the thickness will vary according to the process.

Question 32

Activation of a Substrate. Does anybody know the exact definition of "activating" a substrate before thermal spray on this substrate? The background of my question is, I found a patent which claims to protect this technology. It is reported, that first of all, the substrate has to be profiled and the substrate will be "activated." After this process, normal plasma spray (APS) should take place. In my opinion, profiling by, for example, shot blasting is not a technology to protect.

Answer 32.1: The definition of activation given by the ASM Handbook *Surface Engineering* is: "Activation—(1) the changing of a passive surface of a metal to a chemically active state. (2) The (usually) chemical process of making a surface more receptive to bonding with a coating or an encapsulating material." Certainly the latter definition is important in some areas such as the painting of aluminum automotive body shells where passivated surfaces are activated by HF-containing etches immediately prior to painting. In the field of thermal spraying this seems less necessary. The grit-blasting process generally removed passive films and leaves the surface reasonable active for many materials (e.g., most steels), but this surface will contaminate and repassivate in time—hence the instructions to coat soon after blasting in many specifications. For some very active substrate materials, e.g., aluminum, it is conceivable that the surface could benefit from activation prior to spraying. However, the energy dissipation from material splatting onto the surface can probably break up and disrupt thin passive layers, so I do not think it is likely to be of major interest in anything but a few very specialist applications. I've tested some plasma sprayed alumina coatings on aluminum alloy (7075-T6), and we found that activation had only a slight effect on bond strength. Reducing the water in the blasting lines had a much bigger effect.

Question 33

Thermal Conductivity of PSZ. Does anyone have information on the thermal conductivity of zirconia applied with a thermal spray?

Answer 33.1: One of the most recent publications, including measurements (400 to 800 K), is A.J. Slifka, B.J. Filla, J.M. Phelps, G. Bancke, and C.C. Berndt, "Thermal Conductivity of a Zirconia Thermal Barrier Coating," *J. Therm. Spray Technol.*, Vol 7 (No. 1), 1998, p 43-46.