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THE HAGUE, 19-23 MAY 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a report of the "9th International Thermal Spraying Conference," held in The Hague, Netherlands, 19-23 May 1980. Thermal spraying is a technique whereby protective coatings are formed through melting and high velocity deposition of materials onto substrates. The high temperatures for melting are achieved through combustion, electric-arc, or within a plasma. The Conference, though highly technologically oriented, also focussed on the scientific bases of processes and materials. The applications cited and discussed included corrosion and wear resistant coatings, erosion resistant

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coatings, thermal barriers, gas turbine applications, electrical applications, plastic coatings.

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9TH INTERNATIONAL THERMAL SPRAYING CONFERENCE
THE HAGUE, 19-23 MAY 1980

Approximately every three years, thermal sprayers of the world unite to exchange stories of of success, recount claims, and discuss developments in this rapidly expanding and, frequently, essential process in by which protective coatings are formed by the spraying of molten materials. Having grown well beyond the "band-aid" stage, thermal spraying is now starting to displace the tried-and-true processes of electroplating, CVD (chemical vapor deposition), and PVD (physical vapor deposition) in the protection of materials for service in difficult environments and for the salvaging of expensive-to-replace machine components.

So it was that the 9th International Thermal Spraying Conference (ITSC) convened in The Hague, Netherlands, 19-23 May 1980. The majority of the individuals who attended came from those countries which produce both spraying equipment and materials (e.g., USA, UK, West Germany, and France). Some 75 papers were presented by rapporteurs, who succeeded unevenly in getting the message across. (In one session, a French rapporteur reviewed both a Polish paper and a Japanese paper, neither of which was in clear English; the results were interesting).

It would be appropriate here to review some of the basic facts about thermal spraying. Thermal spraying is a generic term encompassing oxyacetylene or flame spraying (frequently, "gas spraying" to the Europeans), electric arc, and plasma spraying. The purpose of all these techniques is to bring about the melting and ultrarapid solidification of the material to be deposited. The result is a deposit not unlike that obtained through splat-cooling, and, in fact, the procedure gives rise to the same sort of metastable phases. The molten particles are deposited rapidly on a surface which has been grit-blasted to assist in anchoring the coating. In recent years, intermediate, adhesion-enhancing "bond-coats" such as Ni-Al and Mo have been employed; this frequently precludes the requirement for a roughened surface. The coating evolves by the build-up of interlocking flattened particles, each of which is comprised of fine grains about 1 micron in diameter. One aspect of such coatings that is commonly encountered is porosity, which results from the chaotic manner of deposit build-up; this can be mitigated however, and sometimes totally avoided, either by increasing particle velocity or by post-spray treatment, such as rolling or plastic filling, for metals, and by sintering or laser processing for ceramics.

The range of sprayed materials is enormous and their utility is vast. In fact, virtually any material can be sprayed; the principal requirement is that chemical decomposition does not occur prior to melting. The substrate material is likewise virtually unlimited. (I have a styrofoam coffee cup on my desk that has been oxyacetylene sprayed with zinc!) Much work has gone into spray-gun design. High velocity spraying and controlled environments play an increasingly prominent role in the forming of protective coatings for the aerospace industry. Plasma guns of 250 KW have been manufactured, but most plasma spraying is carried out in the 40 to 80 KW range.

The use of thermal-sprayed coatings has broadened considerably in recent years; thermal spraying now has applications in tribology, corrosion protection, and thermal barrier systems. Ceramics such as oxides, carbides, and borides are sprayable, as are cermets. These materials, and metals, can be sprayed in free-standing form (for filters, crucibles, etc.). A fair number of plastics can be sprayed, but like other such techniques, spraying requires a "fine hand" to achieve a good coating.

The conference, which was divided into 14 sessions, included presentations on applications, quality control, processes and equipment, post-spray treatment, developments in spraying materials, coating characteristics, and properties of sprayed coatings. The papers ranged from scientifically oriented subjects (e.g., acoustic emission and Mössbauer spectroscopy) to the bread-and-butter operations of the spraying industry (e.g., corrosion protection of steel bridges and hard facings, to name only two).

Groups with a wide variety of professional interests regularly attend these conference; these include equipment designers and manufacturers, materials specialists (i.e., powder metallurgists and ceramicists), users, and testers. It is clearly the last-named area which has the greatest needs; the industry generally demands reproducible means of quality testing and non-destructive evaluation. While much work is being done to evaluate porosity and adhesion directly, there is a limited number of techniques available for evaluating and predicting a coating's behavior (more on this below).

The first morning opened on an upbeat note with a welcoming talk by the Netherlands Minister for Science Policy, Dr. A.A. th. M. van Trier, who outlined steps being taken by the Netherlands government to give innovation a shot in the arm. The solution, Dutch-style, will involve enhanced university-industry interactions yielding, it is hoped, a greater appreciation for problems facing society today. This oft-repeated theme was perhaps appropriately addressed to this particular group, whose main goal in life is to make things perform better, longer.

The second address was given by Prof. J.H. Zaat of Eindhoven University, the Netherlands, who, as it were, gave the conference its marching orders: Go do fundamental research on thermal spraying! His suggested areas of concentration concerned the development of a "consolidated spraying theory," that is, the ability to predict (and thus, to control) the technological properties of a sprayed part. Zaat expressed the opinion that studies should be carried out on both the thermal and aerodynamic properties of sprayed gases and particles. However, he noted that the materials aspects of the problem, the starting material and how it is constituted, and the resulting characteristics of the coating, would probably be neglected at this conference, as they were neglected all too frequently at similar conferences. Zaat correctly maintained that it is the interaction of process-and-materials that holds the key to effective optimization.

The final talk of the opening ceremonies was given by Prof. H.D. Steffens of Dortmund University, FRG, who placed thermal spraying in the perspective of competitive coating technologies. According to Steffens, there is clearly no "Royal Coating". What is perfect for aerospace applications, for example, may not be suitable for oxide substrates in solid-state electronics. Put simply, Steffens properly reminded the attendees that they should grow out of their own parochialism and look first at the problem that is being evaluated and not, principally, at a process in search of a use.

The papers which were reviewed by the rapporteurs and discussed by the authors and attendees generally covered techniques, applications, and testing (again, the last item represents an elusive and long-sought goal of coating technologists generally). Clearly, the technique of the day was chamber spraying which is also called low pressure spraying or vacuum spraying. There was also considerable interest in plasma spraying in a reduced pressure environment of the order of 50 torr. A number of papers were presented on this topic; their primary thrust was towards aerospace, which dramatically demonstrated the special features of this method and the impact it will have on the future of protective coatings. Of special interest was a paper by J.R. Rairden (General Electric, Schenectady, NY) on the properties of high-velocity, plasma-sprayed NiCrAlYC coatings. The micrographs of the coatings which he displayed looked very much like wrought alloy. Clearly, there is no question of high density, and this, too, was seen in a paper by V. Wilms (MTU-Munich), which discussed hot-gas corrosion of low-pressure plasma-sprayed coatings. The most important feature of this new process is prior cleaning of the substrate surface through a method of transferred arc "sputtering." This leaves the surface clean and able to accept subsequent supersonic plasma gas and melt. The interface is barely discernible, and an excellently adhered coating is obtained.

The prospects for low-pressure, high-velocity spraying are most exciting, and industry is apparently getting the message (e.g., the spraying of conductors having electrical conductivities approaching bulk values, and the spray formation of alumina substrates with smoothnesses enabling them to be used as substrates in electronic device technology—though the latter can be done effectively through the use of fine particles and excellent spray techniques).

Other developments included a discussion of shrouds by J.M. Houben (Eindhoven Univ.), who examined the fundamental aspects of plasma spraying and introduced concepts which would permit novel gun design, including barrel extension and the like. Certainly, there are numerous possible improvements which could increase spray efficiency without costing what low pressure spraying frequently requires (about $250,000 a number!).

In this respect, much is being done to evaluate plasma spray processes. In a particularly interesting paper, A. Vardelle et al., (Universite de Limoges, Belgium), described laser-Doppler anemometry and optical pyrometry which were employed to determine particle velocity and the temperature of the spray stream. The authors went yet a step further, relating the quality of the coating (Al_2O_3) to processing parameters as studied through velocity and temperature. Essentially, the solidified particle size was connected to particle size distribution, temperature and velocity. The authors concluded that viscous flow is important, and that there is a good indication that particle spreading on the substrate terminates prior to significant solidification. One can argue with some of the assumptions and conclusions, but, clearly, this "scientific" approach was gratifying.

Papers on the testing of thermal-sprayed coatings covered nondestructive testing as well as other more damaging tests (e.g., "Hammer" test). Nondestructive testing has been a hot issue for some time, by reason of the fact that any industrial process seeking acceptance must offer quality control of a reproducible sort. Thus, the papers related to testing covered ultrasonic testing, acoustic emission, holographic interferometry, and thermography. The standard ultrasonic tests show limited resolution (i.e., typically, of the order of 1 mm of debonded interface) and reproducibility that is still open to debate. There was a general feeling of optimism, however, and much interest was indicated. In a very interesting paper, H. Reiter and coworkers (Univ. of Bath, UK) presented a new approach that uses ultrasonic attenuation to detect flaws in plasma-sprayed metal coatings on steel plate. The ultrasonic results were satisfactorily correlated with cross-sectional micrographs of the coatings. We may finally be on the verge of an acceptable nondestructive testing technique for sprayed coatings.

The protection of steel structures in marine and industrial environments by means of flame- and arc-sprayed active metal coatings has found wide approval but still receives only limited use. The American Welding Society, in a test series published in 1974, concluded that thermal-sprayed aluminum and zinc-coated steel, with or without subsequent painting, performed remarkably well after 19 years of exposure in a range of environments—from total submergence in seawater to exposure in a dry industrial atmosphere. If the coating can be made to adhere—and it can be made to do so—then corrosion protection will be assured through very substantial and long-term cathodic protection.

Papers given by representatives of the Norwegian Highway Department outlined their experiences with bridge protection by means of sprayed aluminum. This was the third in a series of papers from this group; the first was presented at the 7th ITSC in 1973. R. Klinge, the chief engineer for the department, found it remarkable that more general use was not being made of corrosion protection through flame spraying and noted that his government finds the metallization of a small bridge used by only one farmer economically justifiable.

M.J. Round (Metallization Services Ltd., UK) conveyed a very optimistic message for the future of electric-arc-sprayed active metal corrosion protection, and reviewed a number of experiences in the field. Speakers from the UK Ministry of Defence and Y-ARD Consultants (Glasgow), in a joint presentation, continued in the same vein on the behavior of coatings for load-bearing applications (e.g., Cr_2O_3, Stellite, WC) in seawater. A group from Stony Brook (State Univ. of NY) discussed their experiences with open-circuit potential measurements and weight-loss studies of flame-sprayed coated steel that had undergone cavitation erosion in seawater. The coatings were aluminum, zinc and a Zn-15 wt.% Al. In this example, a post-spray thermomechanical treatment of the coatings to effectuate pore closure was especially interesting. Japanese workers reported on the establishment of a galvanic series for sprayed coatings based on electrochemical potential measurements in seawater.

As regards low-temperature corrosion in seawater, two papers held particular interest for the participants. One was a report by R. Sulit, H.H.J. Vandervelt, and V.D. Schaper (all of the US Navy) on corrosion control through the use of wire-sprayed aluminum for shipboard protection above deck, which represented a major breakthrough for acceptance of the process. Naval authorities, out of necessity, exert great care in the acceptance of a new process for fleet use. Clearly, after considerable testing and evaluation, the US Navy has now recognized the great utility of corrosion protection through thermal-sprayed aluminum. The Navy has sprayed propulsion-plant steam turbine valves, piping, and weather-deck walkways, etc. The acceptance of thermal spraying will reduce much of the labor-intensive shipboard drudgery which in the past was required of crew members. This report was most welcome and will undoubtedly contribute to the recognition of thermal spraying as an effective means of seawater corrosion protection.

The second major paper on marine corrosion, by N. Jodorn and M. Nadeau, discussed the metallizing of the 1-kilometer-long Pierre-Laporte Bridge in Quebec, Canada, presumably the largest *on site* flame-spray project of its kind. (The Forth Road Bridge, Queensferry, Scotland, is the largest structure to have been metallized.) The three-span Pierre-Laport bridge was constructed some 10 years ago, and was originally protected against corrosion by a system of lead silico-chromate, oil, and alkyd paint. However, maintenance and paint retouching procedures became expensive, and the government began a cost evaluation of metallization. To quote from the report by Jodoin and Nadeau, "A comparative cost analysis was made covering a 130 µm thick conventional paint system, with a life of approximately 8 years, requiring frequent touch-ups and the erection of mobile scaffoldings, and, the alternative, expenditures for a 175 µm zinc coating with a probable life of 20 to 25 years, requiring no major touch-ups. After taking into consideration the sums involved, the interest interest rates and the estimated (3%) (sic) annual increase in labor costs...the ministry decided in favor of metallizing the bridge."

Of course, special problems arose due to the fact that the bridge had been previously painted, but even with that, the Canadians expect no major maintenance on the bridge until the turn of the century! Needless to say, the potential cost savings are enormous.

The message is clear: vastly improved corrosion protection is available through the use of thermal spraying. In the long view, metallization can be shown to offer greater economic advantages, increased energy conservation, and, overall, more effective protection.

Probably some of the limitations on the adoption of thermal spraying techniques stem from a combination of conservatism, ignorance, and simple labor politics (what does one do with the painters [not to mention their unions] who would be displaced from their perennial postures, perched high over so many water-ways?). These problems, as well as the economics and the feasibility of spraying prior-painted structures, need careful consideration.

In some cases, the viewpoint expressed is one of caution. Not so many years ago I asked a constructor of offshore oil-drilling rigs why more general use was not made of thermal spraying on those gigantic structures. I was told about the possibility of sparking when a rusty tool is dropped on an aluminum-sprayed deck (the thermite reaction?). Then again, negative experience (because of jobs poorly done) and misinformation often retard the acceptance of a new (different) technology.

In the long run, inflation may be the greatest stimulator of innovation, when it comes to the acceptance of cost-saving processes such as thermal spraying. And that is exactly what the proponents of the process say. They believe that time is on the side of thermal spraying, and that the economics will eventually force its utilization for corrosion protection as well as for other materials-protection and salvaging applications.

For certain applications, post-spray treatment is necessary to attain optimum properties. Hardfacing through thermal spraying of carbides, for example, can be made more effective by post-spray sintering. This improves adhesion and increases density. Fusing which employs the flame of the spray torch, is frequently used for this purpose. In recent years there has been discussion in the literature of laser treating of plasma sprayed ceramics. (But, to some extent, chamber spraying will short-circuit this development.) A rather exciting approach to post-spray densification was reported by researchers at SKF and Eindhoven University. H.B.V. Nederveen et al. have "hot isostatic" pressed and plasma-sprayed WC-Co hard-face coatings to improve hardness, wear resistance, and corrosion resistance. Their results, while still preliminary, are most interesting and point to the need for further study.

The overall impression one got from the meeting was a consensus that thermal spraying has been proved suitable for an incredibly wide range of industrial applications. As both a corrective and improvement technique, thermal spraying, in all its forms, has indeed arrived. the book of preprints, some 437 pages in length, attests to the present activity in the field. The proceedings volume, which was distributed to participants prior to the meeting, was published by Nederlands Instituut voor Lastechniek, Laan van Meerdervoort 2-B, 2517 AJ, the Hague, Netherlands.