ORGANIC finishing

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Current and Future Applications of Cold Spray Technology

Cold spray is one of the many names for describing a solid-state coating process that uses a high-speed gas jet to accelerate powder particles toward a substrate whereby metal particles plastically deform and consolidate upon impact. The term "cold spray" refers to the relatively low process temperature involved in the process, which is typically much lower than the melting point of the spray material.

Although the concept of cold spraying metallic materials onto substrates goes back to the early 1900s, it was not until the 1980s that the applicability of this technology was demonstrated at the Institute of Theoretical and Applied Mechanics of the Russian Academy of Sciences in Novosibirisk. Because adhesion of the metal powder to the substrate and deposited material is achieved in the solid state, the characteristics of cold spray deposits are quite unique, making cold spray suitable for depositing a wide range of traditional and advanced materials on many types of substrate materials, especially in non-traditional applications that are sensitive to the temperature of the process.

Some of the characteristics of cold spray include the ability to form dense deposits with extremely low oxygen content, free of residual tensile stresses, grain growth, recrystallization zones, and phase changes. Certain materials may even experience grain refinement at the nanometer scale. These attributes make cold spray uniquely suitable for depositing a range of advanced and temperature-sensitive materials. Today, cold spray is increasingly being used in a number of industries, including aerospace, energy, and military (Figs. 1 and 2).

Figure 1: Field repair of corrosion surface damage by low-pressure cold spray.

HOW DOES COLD SPRAY WORK?

Back in the 1980s, during the practical development of cold spray technology, two methods of injecting the spray materials into the nozzle were patented, leading to what is known today as high pressure (injecting the powder prior to the spray nozzle throat from a high-pressure gas supply)[1] and low pressure (injecting the powder in the diverging section of the spray nozzle from a low-pressure gas supply).[2]

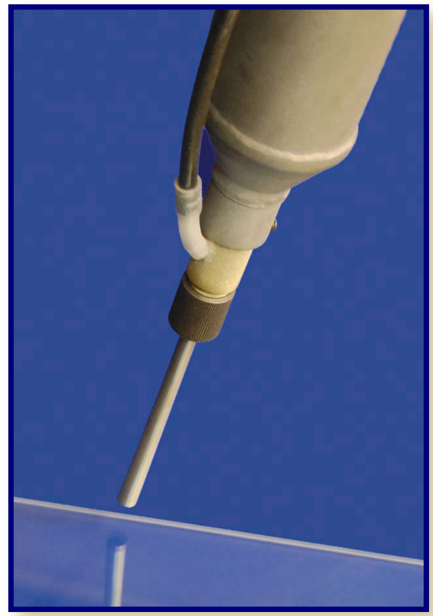

Figure 2: Cold spray fabrication of conductive busbars over tin oxide-coated glass for heated glass applications.

In high-pressure cold spray (Fig. 3), helium or nitrogen at high pressure (up to 1,000 psi) is preheated (up to 1,000°C) and then forced through a converging-diverging *DeLaval* nozzle. At the nozzle, the expansion of the gas produces the conversion of enthalpy into kinetic energy, which accelerates the gas flow to supersonic regime (1,000 m/s) while reducing its temperature. The powder feedstock is introduced axially into the gas stream, prior to the nozzle throat. The accelerated solid particles impact the substrate with enough kinetic energy to induce mechanical and/or metallurgical bonding.

In low-pressure cold spray (Fig. 4), air or nitrogen at relatively low pressure (80–140 psi) is also preheated (up to 550°C), then forced through a *DeLaval* nozzle. At the diverging side of the nozzle, the heated gas is accelerated to about 600 m/s. Powder feedstock is introduced downstream in the diverging section and accelerated toward the substrate.

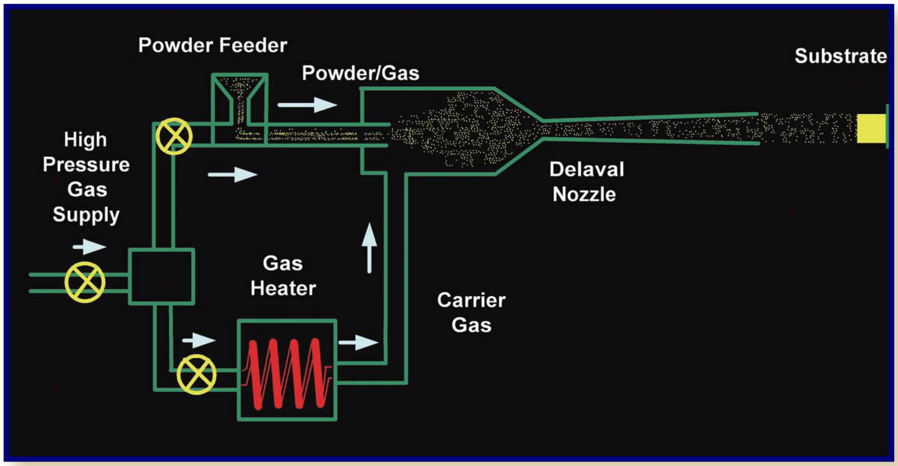

Figure 3: Operating principle of high-pressure cold spray.

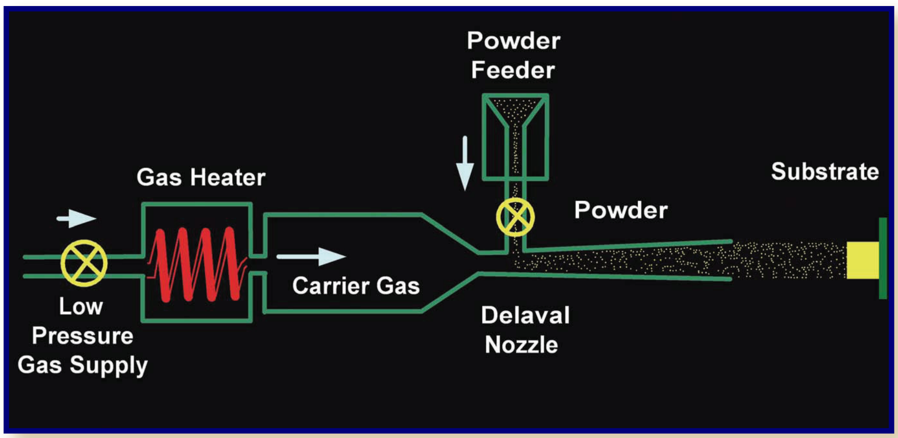

Figure 4: Operating principle of low-pressure cold spray.

Figure 5: Commercially available low-pressure cold spray systems, including portable systems intended for field operation.

(Image courtesy of CenterLine Windsor, Ltd.)

As the applicability of cold spray technology expands to new and unique areas of application, there has been an increasing number of commercially available, ready-to-use cold spray systems introduced into the marketplace (Fig. 5).

FUTURE TRENDS

There are new developments in cold spray technology, including shock-wave-induced spraying,[3–6] whereby the fast opening/closing of a control valve downstream of a high-pressure gas source generates a pulsed (10–30 Hz) heated supersonic flow (Fig. 6). The pulsed flow is used to simultaneously accelerate and heat the powder, which is introduced in a cylindrical nozzle. In contrast with cold spray, a *DeLaval* nozzle is not required, and powders can gain additional energy during acceleration. This effectively facilitates bonding for a wide range of engineering materials, including steels, titanium, and cermets. Also, the intermittent gas flow lowers gas consumption and increases energy efficiency.

ADVANCED APPLICATIONS

Cold spray technology falls under the larger family of thermal spray processes, and it is not here to replace any of the well-established thermal spray methods. Instead, cold spray technology is expected to supplement and expand the range of applications for thermal spray.

In its current state, cold spray is increasingly used in a variety of industries for corrosion mitigation of sensitive materials, such as: magnesium and aluminum alloys; surface restoration; manufacturing of sputtering targets; fabrication of busbars on heated glass; deposition of WC-Co for hard-chrome replacement coatings; electrical and thermal conductive coatings for transition surfaces; braze joint preparation; and deposition of NiCrAlY bond coats for thermal barriers. For many of these applications, cold spray presents itself as a more economical method because it can actually eliminate or reduce fabrication steps.

For other applications, cold spray is simply the only viable solution, especially for an increasing number of

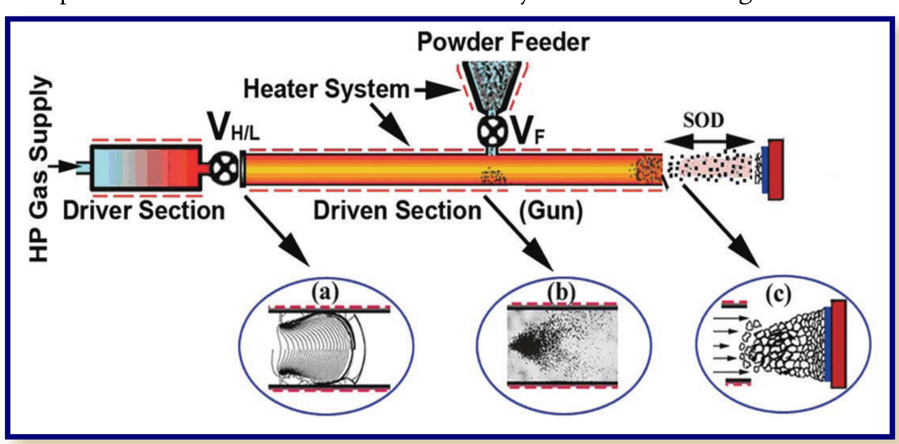

Figure 6: Shockwave-induced spraying (SISP).

Figure 7: Array of thin-film photovoltaic panels powering an entire building at the University of Toledo campus, Toledo, Ohio, USA.

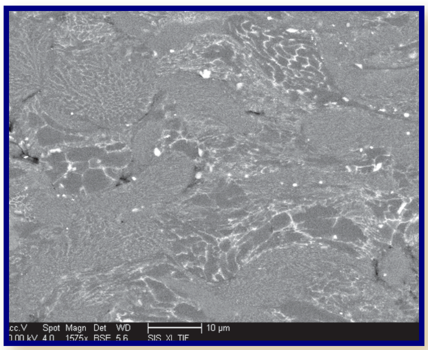

Figure 8: Nano-structured 2618 aluminum alloy deposited by the cold spray process.

non-traditional applications. While environmental and health & safety regulations have become more stringent, interest in cold spray has grown as a potentially greener alternative.

As the technology evolves it is anticipated that cold spray applicability will continue to expand to more non-traditional applications, such as photovoltaic, wind, medical, and architectural. In photovoltaic applications, cold spray could be used for the fabrication of complex conductive patterns in solar cells (Fig. 7). Wind power generation may be able to make use of cold spray to enhance surface performance in components made of advanced polymer-matrix composites.

In the medical field, cold spray has already been demonstrated to effectively apply hydroxyapatite (HAP), a well-known bio-compatible material, to a number of substrates without compromising the integrity of HAP. Architects can take advantage of cold spray to create unlimited aesthetic metallic patterns on any metal or ceramic substrate.

NANOTECHNOLOGY AND SMART STRUCTURES

Some other non-traditional applications involve the utilization of advanced materials, such as nano-structured and amorphous materials. In nano-structured materials, grain sizes are extremely small and provide mechanical advantages such as extreme fracture toughness while maintaining a high level of material strength. Nano-crystallinity is quite sensitive to process temperature, and cold spray can effectively be used without compromising their beneficial microstructure (Fig. 8).

Because of its low-temperature deposition, cold spray can be used to embed micro-sensors, along with functional coatings, on surfaces for smart structures. These structures would have the ability to provide real-time information related to materials performance or environmental conditions. There are a number of emerging enterprises that are focusing on providing solutions for sensing, database management, and prognostics analysis in bridges, power grids, wind turbines, aircrafts, automobiles, ships, pipelines, and construction equipment. The future of cold spray relies on its ability to deposit advanced materials onto a diversity of substrates with minimum thermal penalty and cost. These are the cornerstones that will define the direction and opportunities lying ahead for this technology.

NOTES

1. Alkhimov, A.P., Papyrin A.N., Kosarev, V.F., Nesterovich, N.I., Shushpanov, M.M. Gas-dynamic spraying method for applying a coating. US Patent 5,302,414, Apr. 12, 1994.
2. Kashirin, A.I., Klyuev, O.F., Buzdygar, T. V. Apparatus for gas-dynamic coating. US Patent 6,402,050, June 11, 2002.
3. Jodoin, B., Richer, P., Bérubé, G., Ajdelsztajn, L., Yandouzi, M. Pulsed-gas dynamic spraying: process analysis, development and selected coating examples. *Surface and Coatings Technology* 2007;201(16–17): 7544–51.
4. Yandouzi, M., Jodoin, B. Microstructure and properties of WC-based coatings prepared by pulsed gas dynamic spraying process: influence of process variables. *Surface and Coatings Technology* 2008;203(1–2): 104–14.
5. Yandouzi, M., Jodoin, B. WC-based composite coatings prepared by the pulsed gas dynamic spray process: effect of the feedstock powders. *Surface and Coatings Technology* 2008;202(16): 3866–77.
6. Yandouzi, M., Sansoucy, E., Ajdelsztajn, L., Jodoin, B. WC-based cermet coatings produced by cold gas dynamic and pulsed-gas dynamic spraying processes. *Surface and Coatings Technology* 2007;202(2): 382–90.

BIO

Dr. Julio Villafuerte is the director of research & development at CenterLine Windsor Ltd., one of North America's premier designers and manufacturers of metal forming and welding equipment, supplying many of the world's leading vehicle manufacturers. Dr. Villafuerte, also currently an adjunct professor for the University of Waterloo, with active involvement in lecturing and research, holds Ph.D. and master's degrees in mechanical & materials engineering from the University of Waterloo. He has more than 15 years of experience in welding and materials processing technology and has, for the last few years, committed to research and dissemination of the new cold gas dynamic spray technology.

Dr. Villafuerte is very active in the industrial community, including the International Thermal Spray Association and ASM's Thermal Spray Society. He is the author of numerous technical publications and regularly volunteers as technical/strategic advisor to a number of professional and academic committees. Dr. Villafuerte serves as a technical reviewer for the ASM Journal of Materials Engineering and Performance, *the* Journal of Photochemistry and Photobiology & Chemistry, *and* Surface and Coatings Technology.