JOURNAL OF COATING TECHNOLOGY AND INNOVATION
2023, VOL. 1, ISSUE 1
https://doi.org/10.61577/jcti.2023.100001

RESEAPRO JOURNALS

MINI REVIEW

OPEN ACCESS

Development to industrial applications: the evolution of cold spray technology

Jianhong He

Department of Material Science, Oerlikon Metco, Westbury, New York, USA

ABSTRACT

The domains of thermal spray, additive manufacturing, and space propulsion have all shown a great deal of interest in cold spray technology. It entails using supersonic gas jets to deposit powders below their melting points. This method has several uses, ranging from coatings to part repair and material property enhancement. The two main varieties, High-Pressure Cold Spray (HPCS) and Low-Pressure Cold Spray (LPCS), each have their own benefits and have sparked advancements in the industry. The goal of this study is to present a thorough overview of cold spray technology, covering its development over time, underlying principles, and industrial uses. A significant factor in the development of cold spray technology and its subsequent widespread use across a range of industries was the National Center for Manufacturing Sciences (NCMS) in the United States. Many benefits come with cold spraying, including material properties preservation, near-wrought properties, and a wide range of material applications. Repairing military hardware, building rocket engine parts, and creating lightweight combustion chambers for space travel are examples of successful applications. In conclusion, cold spray technology is still developing and becoming more well-known, demonstrating its potential to lead to revolutionary breakthroughs in both space exploration and manufacturing.

KEY WORDS

Cold spray technology, Supersonic gas jets, Industrial uses, Space exploration, Manufacturing

ARTICLE HISTORY

Received 17 August 2023; Revised 01 September 2023; Accepted 08 September 2023

Introduction to Cold Spray Technology

High power impulse magnetron sputtering (HiPIMS) is a mCold spray is an innovative solid-state spray process distinguished by its ability to deposit a wide variety of powders—including metals, metal alloys, metal blends, polymers, and cermet powders—at temperatures below the material melting point [1].

This technique is achieved through the ingenious utilization of a supersonic nozzle that is paired with pressurized and heated inert gas [2].

The applications of cold spray technology are versatile and impactful, facilitating the creation of new parts in the realm of cold spray additive manufacturing (CSAM), the meticulous repair of existing parts, and the fortification of surface coatings to enhance base material properties [3-5]. These coatings are instrumental in providing protection against common issues such as corrosion and wear, serving as a testament to the remarkable adaptability and utility of cold spray processes [5].

Historical background

The innovative cold spray process, a significant advancement in material science, was introduced by talented Russian scientists A. Papyrin and A. Alkhimov at the Siberian Branch of the Russian Academy of Sciences, located in the vibrant city of Novosibirsk, Siberia, during the dynamic mid-1980s [5]. Before the inception of the cold spray process, traditional methods employed for manufacturing metal coatings predominantly included dissolving metals in chemical baths through chemical or electric plating techniques, melting them using thermal spray coating methods, or vaporizing them with various chemical vapor deposition (CVD) and physical vapor deposition (PVD) processes [6].

Types of Cold Spray Process Technologies

Delving into the intricacies of cold spray process technologies, two prominent categories emerge, i.e., high-pressure cold spray (HPCS) and low-pressure cold spray (LPCS) [5,6]. In the realm of HPCS, an intriguing phenomenon unfolds as a robust gas jet materializes via the passage of high-pressure gas, usually spanning the range of 1 to 5 MPa, through a specially designed converging-diverging nozzle [7,8]. This intricate setup culminates in the attainment of supersonic flow, a pivotal feature that propels solid particles, typically measuring less than 100 microns in diameter, to astronomic velocities in the realm of 1200 m/s, all within a scorching jet of heated gas soaring up to 1100°C [5-8]. Ultimately, these accelerated particles find their destination on a rigid substrate surface, establishing a robust bond and infusing the surface with renewed vigor [5-8]. Transitioning to LPCS, an equally captivating narrative unfolds, with compressed air or nitrogen playing a pivotal role at modest pressures, ranging from 0.5 to 1.0 MPa [5-8]. Heat becomes a crucial factor as the gas is artfully preheated to temperatures surging up to 550°C before hurtling through a converging-diverging nozzle, a scene that sets the stage for acceleration to velocities touching 600 m/s [5-8]. These swiftly moving particles then recreate the spectacle witnessed in HPCS, effectively settling on a hardened substrate, hereby encapsulating the essence of LPCS.

Development and Industrial adoption

In the middle of the 1990s, a program known as the National Center for Manufacturing Sciences (NCMS) was established

*Correspondence: Dr. Jianhong He, Department of Material Science, Oerlikon Metco, Westbury, New York, 11590, USA, e-mail: Jianhong.He@oerlikon.com

in the United States. The coating group within NCMS played a pivotal role in advancing cold spray technology [5,9]. They provided support to Dr. Papyrin to carry out a demonstrative project at the University of Toledo and facilitated the creation of a research cold spray system at General Motors Technology Center [10,11]. Dr. Papyrin was instrumental in issuing the very first U.S. license for the cold spray process to ASB Industries, a reputable thermal spray coating company based near Akron, Ohio [11]. With Dr. Papyrin's guidance and the initial efforts of the NCMS coating group, later succeeded by the US Sandia National Lab consortium, significant strides were made in the field of cold spray technology [11,12].

Continuing on this trajectory of innovation, the Sandia research team, under the leadership of Dr. Mark Smith, designed and constructed a custom-built cold spray system that was intricately instrumented [11,12]. This system was utilized to conduct groundbreaking gas dynamics studies of the cold spray process in the United States. The results of these studies were published in a renowned paper titled "Gas Dynamic Principles of Cold Spray" [12], significantly enhancing the scientific understanding of cold spray technology.

Moreover, Sandia National Lab delved into the practical application of cold spray technology by successfully undertaking a time-sensitive repair of a metal component on an earth-orbiting satellite. In parallel developments during the 1990s, a Russian research group introduced the low-pressure cold spray process (LPCS) [13]. This innovative LPCS technology was brought to North America in the mid-1990s by Roman Maev and Emil Strumban at the University of Windsor in Ontario, Canada [5,13].

Capitalizing on the LPCS breakthrough, Centerline, a Canadian company located in Windsor, Canada, has since manufactured and distributed portable cold spray systems to a diverse range of clients across industries such as automotive, mass transit, aerospace, and defense [14]. This expansion of cold spray technology into various sectors has facilitated advancements in material deposition and repair techniques, contributing to the overall progress of manufacturing sciences [15,16].

Advantages of Cold Spray

The advantages of cold spray technology are significant and diverse. One key benefit is the low heat input involved, ensuring that the powder's microstructure and properties remain intact without the risk of oxide formation, alloy decomposition, or entrapment of combustion products [17,18]. Furthermore, cold spray enables the attainment of near-wrought properties, providing a level of quality comparable to traditional manufacturing processes [19]. Another advantage is the flexibility it offers in terms of deposition thickness, allowing for its utilization as an additive manufacturing method [7,20]. Moreover, cold spray boasts high-efficiency levels of up to 80%, making it a cost-effective solution [5]. Additionally, the deposition density exceeds 99%, indicating the high precision and quality of the sprayed materials [20]. Finally, the technology supports a wide range of materials, from soft aluminum to high-strength steels and WC-Co, showcasing its versatility and applicability across various industries [1].

Successful applications of Cold Spray

There are several successful examples showcasing the effectiveness and versatility of cold spray technology. One noteworthy illustration is the pioneering work conducted by Dr. Victor Champagne's esteemed group at the U.S. Army Research Laboratory. In 2007, they established the prestigious Center for Cold Spray Research and Development, dedicating their efforts to advancing the application of cold spray. A groundbreaking achievement of their research was the development of a specialized cold process designed for reclaiming corroded and worn magnesium gearbox housings utilized in UH-60 Black Hawk helicopters and various other military equipment.

Magnesium gearbox housings are renowned for their exceptional lightweight properties; however, they are paradoxically prone to fretting wear and corrosion, particularly in harsh marine environments. Conventional repair and replacement practices for these crucial components incurred substantial costs for the Army and Navy, amounting to millions of U.S. dollars annually in expenses related to UH-60 main transmission and tail rotor gearbox housing assemblies. The implementation of cold spray technology revolutionized this scenario by offering a cost-effective solution for repairing and reclaiming damaged gearbox housings, thereby yielding significant economic benefits for the defense sector.

Recognizing the immense potential and advantages of cold spray technology in military applications, the U.S. Department of Defense formally endorsed its use through the issuance of the military specification MIL-STD-3012, also known as the "Cold Spray Manufacturing Process Standard," in 2008. This pivotal standardization not only highlighted the strategic importance of cold spray technology in defense operations but also propelled its widespread adoption and integration into various defense-related endeavors, further cementing its pivotal role in enhancing operational efficiency and cost-effectiveness.

Cold Spray in Space Propulsion and Community Interests

Manufacturing rocket engine structural parts using the cold spray technique has gained significant popularity in recent times. An example of this cutting-edge technology can be found in a report by NASA (NASA news, May 14, 2021), which highlights the groundbreaking work of the Robotic Deposition Technology (RDT) team based at NASA's Marshall Space Flight Center in Huntsville, Alabama, USA. This team successfully designed and produced innovative, lightweight combustion chambers, nozzles, and injectors using the cold spray method. Furthermore, Airborne Engineering Ltd. (UK) collaborated with Impacted Innovations GmbH (Germany) to create bimetallic combustion chambers for rocket engines through cold spray technology in 2022 (8th International Conference on Space Propulsion, Estoril, Portugal, May 9-13, 2022).

Additionally, Ariane Group, a subsidiary of Airbus based in Germany, also made strides in the field of cold spray technology by unveiling cold-sprayed structural components for rocket engines at the International Thermal Spray Conference in Quebec City, Canada, in 2023 (May 22-25, 2023). Notably, the International Thermal Spray Conference in 2023, which took place in Quebec City, Canada, featured a plethora of presentations - 163 papers, to be precise - touching upon various aspects of cold spray technology, with a particular emphasis on Cold Spray Additive Manufacturing (CSAM). This surge in interest signifies that cold spray technology is quickly emerging as a pivotal topic of discussion within the Thermal

https://doi.org/10.61577/jcti.2023.100001

RESEAPRO JOURNALS

Spray, Additive Manufacturing, and Space Propulsion communities worldwide.

Conclusions

Cold spray technology has undergone a remarkable evolution, transforming into a versatile and impactful process that finds broad applications across various industries due to its exceptional characteristics. The solid-state nature of cold spray technology, coupled with its ability to preserve material properties and accommodate a wide range of materials, makes it a preferred choice for applications such as additive manufacturing, part repair, and coatings in many industrial settings. The historical journey of cold spray technology, starting from its inception by Russian scientists and gaining momentum through industrial adoption supported by initiatives like NCMS, underscores its significant growth and relevance.

Advancements in both high-pressure and low-pressure cold spray processes have further enhanced its capabilities, facilitating efficient material deposition and enabling the achievement of properties comparable to wrought materials. The successful integration of cold spray technology in critical sectors such as military hardware, rocket engine manufacturing, and space propulsion underscores its practical benefits and economic advantages. The increasing interest and active participation in conferences focusing on cold spray technology signal a growing recognition of its importance within the thermal spray, additive manufacturing, and space propulsion communities.

Overall, cold spray technology emerges as a promising innovation driving efficiency and progress in modern manufacturing processes. Despite its numerous advantages, limitations persist, including challenges related to attaining uniform coating thickness and controlling porosity, particularly in complex geometries. Looking ahead, future efforts will concentrate on refining process parameters, designing advanced nozzles, and exploring novel materials to overcome these limitations and broaden the applicability of cold spray technology across diverse industries.

References

1. Poza P, Garrido-Maneiro MÁ. Cold-sprayed coatings: Microstructure, mechanical properties, and wear behaviour. Prog Mater Sci. 2022;123:100839.
2. Maier BR. Investigation of Mechanisms of Metallic Cold Spray Coating Formation and Relevant Corrosion and Irradiation Behaviors. The University of Wisconsin-Madison. 2019.
3. Pathak S, Saha GC. Development of sustainable cold spray coatings and 3D additive manufacturing components for repair/manufacturing applications: A critical review. Coatings. 2017;7(8):122.
4. Vaz RF, Garfias A, Albaladejo V, Sanchez J, Cano IG. A review of advances in cold spray additive manufacturing. Coatings. 2023;13(2):267.
5. Guo D, Kazasidis M, Hawkins A, Fan N, Leclerc Z, MacDonald D, et al. Cold spray: Over 30 years of development toward a hot future. J Therm Spray Technol. 2022;31(4):866-907.
6. Alkhimov AP, Kosarev VF, Nesterovich NI, Papyrin AN. Method of Applying Coatings. 1980.
7. Alkhimov AP, Kosareve VF, Papyrin AN. A Method of Cold Gas-Dynamic Spray Deposition. Dokl Akad Nauk SSSR. 1990;315(5):1062-1065.
8. Singh H, Sidhu TS, Kalsi SB. Cold spray technology: future of coating deposition processes. Frattura ed Integrità Strutturale. 2012;6(22):69-84.
9. McCune RC, Papyrin AN, Hall J, Riggs WL, Zajchowski PH. An Exploration of the Cold-Gas-Dynamic Spray Method for Several Materials Systems. Adv Therm Spray Sci Technol. Materials Park. 1995:1-5.
10. Smith MF, Laboratories SN. Introduction to Cold Spray. High Press Cold Spray. 2020:1-16.
11. Dykhuizen RC, Smith MF. Gas dynamic principles of cold spray. J Therm Spray Technol. 1998;7:205-212.
12. Kashirin AI, Klyuev OF, Buzdygar TV, inventors; Apparatus for gas-dynamic coating. United States patent US 6,402,050. 2002.
13. Irissou E, Legoux JG, Ryabinin AN, Jodoin B, Moreau C. Review on cold spray process and technology: part I—intellectual property. J Therm Spray Technol. 2008;17:495-516.
14. Muehlberger E, inventor; Sulzer Metco US Inc, assignee. Method and apparatus for low pressure cold spraying. United States patent US 6,759,085. 2004.
15. Akedo J. Room temperature impact consolidation (RTIC) of fine ceramic powder by aerosol deposition method and applications to microdevices. J Therm Spray Technol. 2008;17:181-198.
16. Yin S, Meyer M, Li W, Liao H, Lupoi R. Gas flow, particle acceleration, and heat transfer in cold spray: a review. J Therm Spray Technol. 2016;25:874-896.
17. Villafuerte J. Modern cold spray: materials, process, and applications. Springer. 2015.
18. Irissou E, Poirier D, Vo P, Cojocaru CV, Aghasibeig M, Yue S. How to unleash the remarkable potential of cold spray: a perspective. J Therm Spray Technol. 2022;31(4):908-919.
19. Cavaliere P. Cold-Spray Coatings: Recent Trends and Future Perspectives. Cold-Spray Coatings: Recent Trends and Future perspectives. 2017.
20. Sinclair-Adamson R, Luzin V, Duguid A, Kannoorpatti K, Murray R. Residual stress distributions in cold-sprayed copper 3D-printed parts. J Therm Spray Technol. 2020;29:1525-1537.

https://doi.org/10.61577/jcti.2023.100001