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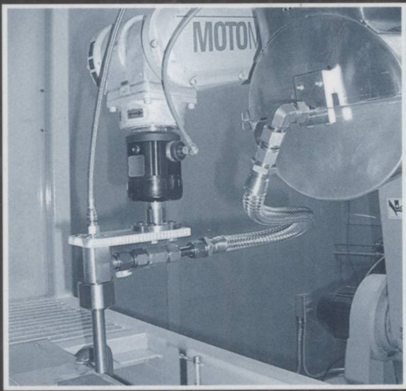

The cold spray materials deposition process

Fundamentals and applications

Edited by Victor K. Champagne

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Preface

The purpose of this book is to convey an understanding of cold gas-dynamic spray and to unravel some of the mystique that has evolved over the years about the possible uses of this process. This book is a compilation of both theory and practical knowledge that provides potential users with the information necessary to recognize the advantages as well as the limitations of cold spray. This has been accomplished by presenting data from a variety of researchers as well as from users of the technology around the globe.

From pioneering work in Russia to upwards of 30 research and industrial installations today, cold spray has evolved from a technical curiosity into an important manufacturing process. The ability of the cold spray process to produce unique coatings that are not attainable with other coating methods has advanced this technology to 'essential' status. Cold spray equipment is commercially available as stationary, robot-controlled, spray systems or as portable, hand-held, systems. The extremely dense, oxide-free, coatings available by cold spray allow this process to be used in such diverse application areas as corrosion control, electrical circuitry, and metals repair. The equipment and capabilities of the cold spray process continue to evolve, opening new application areas on a daily basis.

Cold spray is not a direct replacement for thermal spray, but it does have distinct advantages that make it the most logical choice for certain applications. There are substantial data to suggest that cold spray has a niche in the marketplace; however, it must also be realized that cold spray does have limitations that should be acknowledged in order to prevent misuse of the technology. Cold spray has sometimes been 'oversold', and acceptance of the technology has suffered as a consequence, although a steady increase in equipment sales continues through this writing.

This book is divided into the general areas of cold spray operating and performance considerations and of application demonstrations. Chapters on history, system availability, and costs are also included. The content of this book ranges from mathematically rigorous to descriptive, as is needed to convey the information. It is expected that this book will be useful to cold spray practitioners as well as to those who are considering the use of cold spray for the first time.

It is my intention that this book will provide the means to initiate interest and to spawn the development of those applications appropriate to the cold spray process. I am indebted to the contributing authors for the comprehensive cold spray analysis and for the breadth of application contained in this book.

Victor K. Champagne

Contents

1 Introduction

V. K. CHAMPAGNE, US Army Research Laboratory, USA

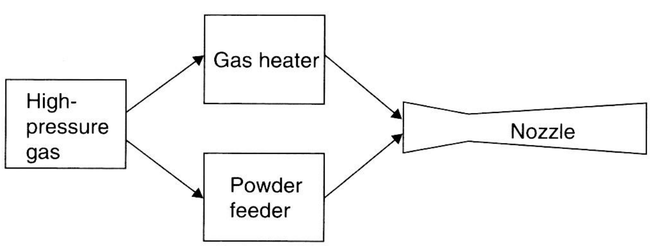
Cold spray is a process whereby metal powder particles are utilized to form a coating by means of ballistic impingement upon a suitable substrate.[1–3] The metal powders range in particle size from 5 to 100 μm and are accelerated by injection into a high-velocity stream of gas. The high-velocity gas stream is generated through the expansion of a pressurized, preheated gas through a converging–diverging nozzle. The pressurized gas is expanded to supersonic velocity, with an accompanying decrease in pressure and temperature.[4–6] The powder particles, initially carried by a separate gas stream, are injected into the nozzle either prior to the throat or downstream of the throat. The particles are then accelerated by the main nozzle gas flow and are impacted onto a substrate after exiting the nozzle. Upon impact, the solid particles deform and create a bond with the substrate.[7,8] As the process continues, particles continue to impact the substrate and form bonds with the deposited material, resulting in a uniform coating with very little porosity and high bond strength. The term 'cold spray' has been used to describe this process due to the relatively low temperatures (−100 to +100 °C) of the expanded gas stream that exits the nozzle.

Cold spray as a coating technology was initially developed in the mid-1980s at the Institute for Theoretical and Applied Mechanics of the Siberian Division of the Russian Academy of Science in Novosibirsk.[9] The Russian scientists successfully deposited a wide range of pure metals, metallic alloys, polymers, and composites onto a variety of substrate materials, and they demonstrated that very high coating deposition rates are attainable using the cold spray process. These experiments are described in detail in Chapter 2. Currently, a variety of cold spray research is being conducted at institutions in dozens of locations world-wide.

The temperature of the gas stream is always below the melting point of the particulate material during cold spray, and the resultant coating and/or freestanding structure is formed in the solid state. Since adhesion of the metal powder to the substrate, as well as the cohesion of the deposited material, is accomplished in the solid state, the characteristics of the cold spray deposit are quite unique in many regards. Because particle oxidation is avoided, cold spray produces coatings that are more durable with better bond strength. The exceptional adhesion of cold spray coatings is in part due to the low temperatures at which the coatings are deposited. One of the most deleterious effects of depositing coatings at high temperatures is the residual stress that develops, especially at the substrate–coating interface. These stresses often cause debonding. This problem is compounded when the substrate material is different from the coating material. This problem is minimized or eliminated when cold spray is used. In addition, interfacial instability due to differing viscosities and the resulting roll-ups and vortices promote interfacial bonding by increasing the interfacial area, giving rise to material mixing at the interface and providing mechanical interlocking between the two materials.

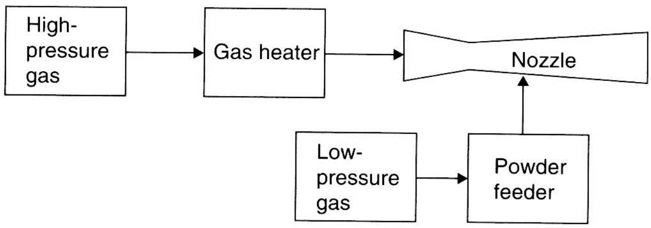
A key concept in cold spray operation is that of critical velocity.[10,11] The critical velocity for a given powder is the velocity that an individual particle must attain in order to deposit (or adhere) after impact with the substrate. Small particles achieve higher velocities than do larger particles, and, since powders contain a mixture of particles of various diameters, some fraction of the powder is deposited while the remainder bounces off. The weight fraction of powder that is deposited divided by the total powder used is called the deposition efficiency. High velocity is necessary for optimal deposition efficiency and packing density, and several parameters – including gas conditions, particle characteristics, and nozzle geometry – affect particle velocity. Chapters 7 through 10 consider the effects of these parameters in detail.

The two principal cold spray system configurations differ in the location of powder injection into the nozzle, and these systems are described in more detail in Chapters 11 and 12. The two configurations are depicted by Figs 1.1 and 1.2. Figure 1.1 shows a system in which the main gas stream and the powder stream are both introduced into the mixing chamber of the converging–diverging nozzle. This configuration requires that the powder feeder be capable of high gas pressure and is most often used in stationary

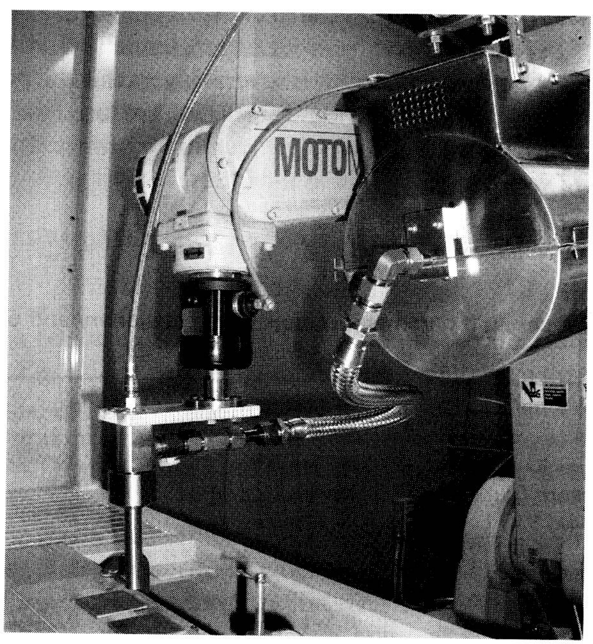


1.1 Typical configuration of the stationary system.

cold spray systems, for which the cumbersome powder feeder is acceptable. Figure 1.2 shows a system in which the powder stream is injected into the nozzle at a point downstream of the throat where the gas has expanded to low pressure. Generally atmospheric pressure air, drawn by the lower pressure nozzle injection point, is used for powder transport from the feeder. Since this system does not require a pressurized feeder, it is often used in portable cold spray systems. Figure 1.3 shows a typical stationary installation. The nozzle (pointed downward) is directed by a robot arm. The gas heater is attached to the robot arm and is coupled to the side of the nozzle



1.2 Typical configuration of the portable system.



1.3 Equipment arrangement of a stationary system.