



# **Cold Gas-Dynamic Spray Glossary**

**Version 1.4**

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## FOREWORD

This glossary is intended to foster development of a shared vocabulary within the rapidly evolving field of cold gas-dynamic spray. It is hoped the *Cold Gas-Dynamic Spray Process Glossary* will serve as a valuable resource for anyone involved with or interested in the application of the technology.

The terms are defined in relation to the field of cold gas-dynamic spraying. We have attempted to be faithful to the ordinary usage of terms to the degree possible. However, as with any specialty, some common words are used in somewhat uncommon ways within this field, and it is those meanings we have tried to capture.

The first edition of this glossary was compiled by culling through a myriad of books, publications, and websites. There has been no intentional act to exclude any process term from this document. The identified terms and their definitions have been created, selected, and modified to attain maximum consistency with existing consensus-based standards while respecting predominant industry usage.

Defining this terminology is an important and controversial challenge we hope will lead to a future standard representing industry consensus. Your comments for improving *Cold Gas-Dynamic Spray Process Glossary* are welcome. Please direct your comments to CGSP Glossary, CenterLine (Windsor) Ltd, 415 Morton Drive, Windsor, ON, N9J 3T8 CANADA; fax (519) 734-2024; e-mail <CGSP.glossary@cntrline.com>.

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# COLD GAS-DYNAMIC SPRAY PROCESS GLOSSARY

## 1. SCOPE

The purpose of this document is to establish standard terms and definitions to aid in the communication of information related to the cold gas-dynamic spray process. One of the goals of this glossary is to encompass all terms, not adequately defined in the dictionary, directly related to cold gas-dynamic spray or allied fields. Both standard and nonstandard jargon, as well as dialect and vernacular terms, are accepted for inclusion in this glossary.

Since this document is a comprehensive compilation of terminology, nonstandard terms are included with cross-references to the corresponding standard terms. Terms that have a process specific definition are preceded with the applicable process-delimiter. Terms defined as verbs are preceded by *v* and where it is necessary to distinguish nouns, they are preceded by *n*. Boldface type indicates standard terms, lightface type indicates nonstandard terms. For the user's convenience, a vertical line preceding a term indicates a revision, i.e., a modification, addition or correction, has been made. A single line denotes a minor change to an existing definition or text. A double line denotes a new term or a major change. All terms are arranged in word-by-word sequence.

This document makes use of both the International System of Units (SI) and U.S. Customary units. The latter are shown within brackets ( [ ] ) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

Safety and health issues and concerns are beyond the scope of this document, and therefore are not fully addressed herein. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*<sup>1</sup> and applicable federal and state regulations.

## 2. REFERENCE DOCUMENTS

The following references were used in preparation of this glossary and may be consulted for additional information. For undated references, the latest edition is recommended. For dated references, subsequent amendments to, or revisions of, any of the publication do not apply to this document.

1. AWS A3.0:2001, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*<sup>2</sup>;
2. ASM/TSS, *Thermal Spray Terminology and Company Origins*, 2001<sup>3</sup>; and,
3. *Webster's Third New International Dictionary of the English Language, Unabridged*<sup>4</sup>.

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<sup>1</sup> Published by the American Welding Society (AWS) or may be downloaded for free through [www.aws.org](http://www.aws.org)

<sup>2</sup> AWS standards are published by the American Welding Society, 550 N.W. LeJeune Rd., Miami, FL, 33126.

<sup>3</sup> Thermal Spray Terminology and Company Origins is published by ASM International, Materials Park, OH 44073

<sup>4</sup> Webster's Third New International Dictionary of the English Language, Unabridged is published by Merriam-Webster, Incorporated, Springfield, MA. It is available from most bookstores.

### 3. TERMS AND DEFINITIONS

For the purposes of this document, the following definitions apply:

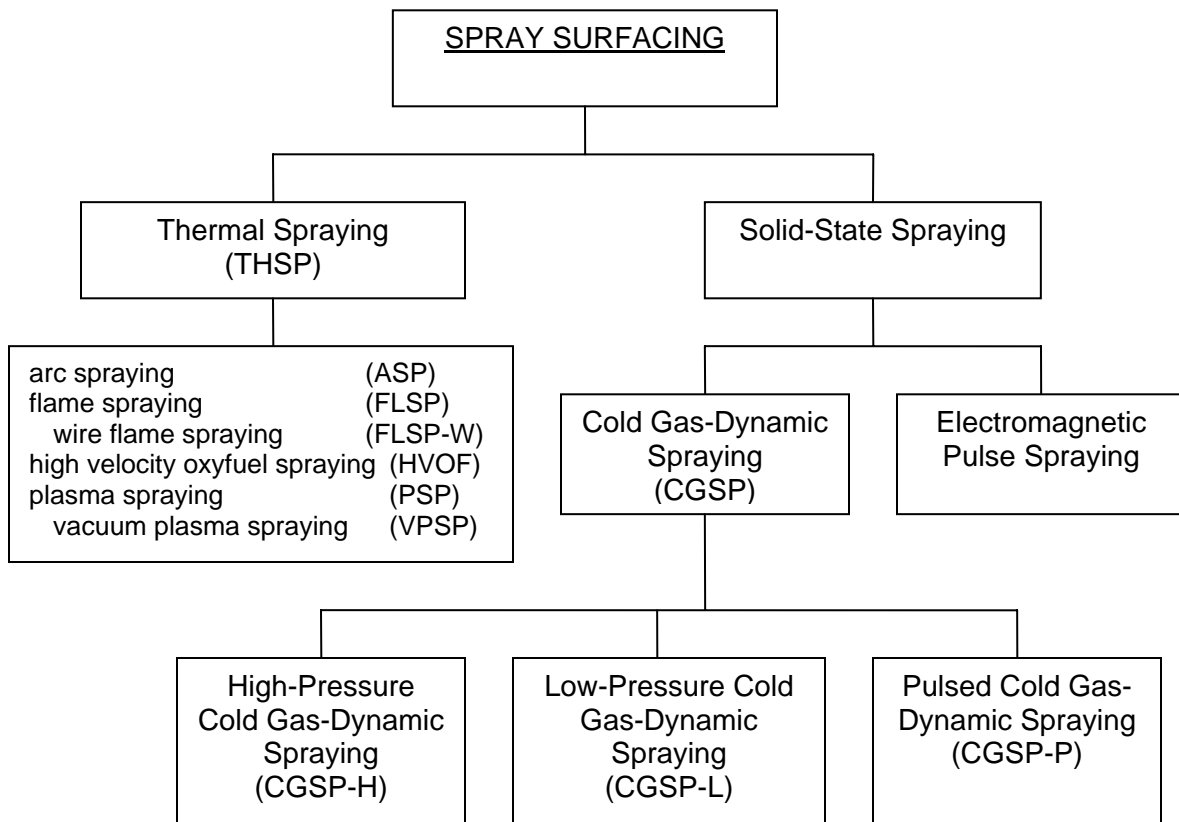
**definition.** A statement of the meaning of a word or word group. The statement may also describe the interrelationship with other terms and association with other relevant information such as tables and figures.

**nonstandard term.** A word or expression used colloquially and provided as a link to the standard term in *Cold Gas-Dynamic Spray Process Glossary*. When used in *Cold Gas-Dynamic Spray Process Glossary*, nonstandard terms are shown in lightface type.

**standard term.** A word or expression recognized in *Cold Gas-Dynamic Spray Process Glossary* as the preferred terminology for use in oral and written language. When used in *Cold Gas-Dynamic Spray Process Glossary*, standard terms are shown in boldface type.

**term.** A word or expression directly related to the cold gas-dynamic spray process with a meaning more specialized or restricted than given in the dictionary.

### 4. PROCESS CHART



## 5. GLOSSARY

### A

**abradable coating.** A sacrificial layer of material applied to a substrate, usually to enable a shape-conforming seal.

**abrasion.** The rubbing or scraping of the surface layer.

**abrasive.** A natural or manufactured substance used to grind, wear down, rub away, smooth, scour, clean, or polish.

**abrasive blasting.** A method of cleaning or roughening a surface by a forcibly projected stream of abrasive particles.

**abrasive wear.** The surface condition resulting from active contact with an abrasive.

adhesive strength. A nonstandard term when used for **bond strength**.

**agglomerated powder.** A substance of clusters of finely divided particles. See also **conglomerated powder** and **flocculated powder**.

**aggregate, n.** A mass of particles held together by mechanical forces.

**air classification.** The separation of powder into particle size fractions by means of an air stream of controlled velocity.

**aligned porosity.** A localized array of porosity oriented in a line.

**alloy.** A substance with metallic properties and composed of two or more chemical elements of which at least one is a metal.

**alloy powder.** Powder prepared from a homogeneous molten alloy or from the solidification product of such an alloy. See also **powder blend**.

**amorphous.** Non-crystalline, or devoid of regular structure.

|| **apparent density.** The weight of a unit volume of solid, which might not be homogeneous.

|| **apparent hardness.** The indicated solidity and firmness of a solid, which might not be homogenous.

**asperity.** A small-scale topographical surface irregularity such as a peak, protuberance.

|| **atomization.** The dispersion of a material into fine particles by a rapidly moving gas, liquid stream, or by mechanical dispersion.



**atomized powder.** A powder produced by the dispersion of a molten material into fine particles by a rapidly moving gas, liquid stream, or by mechanical dispersion.

**automatic spraying.** Spraying with equipment requiring only occasional or no observation and no manual adjustments during its operation. See also **manual spraying, mechanized spraying, robotic spraying,** and **semiautomatic spraying.**

**axial injection.** Introduction of a material along an axis parallel or coincident with the axis of the spray jet.

## B

**babbitt metal.** Nonferrous bearing alloys consisting mainly of various amounts of copper, antimony, tin, and lead.

**backing.** A material or device placed against the back side of a substrate to facilitate the spray process or support the substrate.

**bead.** See **spray deposit bead.**

**binder.** A cementing medium used in producing composite or agglomerated powders.

**blast helmet.** Personal protective device enclosing the person's head in a loose-fitting hard shell, directing fresh air to the wearer, and protecting the head and neck from flying particles generated by abrasive blasting.

**blast hood.** Personal protective device enclosing the person's head and neck in a loose-fitting covering, and protecting the head and neck from flying particles generated by abrasive blasting.

**blasting.** See **abrasive blasting.**

**blended powder.** Thoroughly intermingled powder containing materials of substantially similar chemical composition. See also **mixed powder.**

**block sequence.** A combined longitudinal and cross-sectional sequence for a continuous multiple-pass spray deposit in which separated increments are completely or partially sprayed before intervening increments are sprayed. See Figure 1(a). See also **cascade sequence, continuous sequence,** and **cross-sectional sequence.**

**bond.** See **covalent bond, ionic bond, mechanical bond,** and **metallic bond.**

**bond coat.** A coating layer applied to a substrate to improve the adherence or performance of subsequent layers.

**bonding force.** The attractive force holding atoms together. See also **covalent bond, ionic bond,** and **metallic bond.**

**bond specimen.** The test specimen on which a spray deposit has been applied to determine the bond strength and spray deposit strength.

**bond strength.** The force per unit area required to separate a spray deposit from the substrate.

bottle. A nonstandard term when used for **gas cylinder**.

**bow shock.** A flow discontinuity in the spray feedstock-laden spray jet caused by deceleration and deflection of the gas flow ahead of the substrate. See Figure 2. See also **compressed layer** and **free jet**.

**brittleness.** The tendency of a material to fracture without first undergoing significant plastic deformation.

**buildup.** A surfacing variation in which surfacing material is deposited to achieve the required dimensions. See also **buttering**, **cladding**, and **hardfacing**.

buildup sequence. A nonstandard term for **cross-sectional sequence**.

**buttering.** A surfacing variation depositing surfacing metal on one or more surfaces to provide metallurgically compatible metal for a joint. See also **buildup**, **cladding**, and **hardfacing**.

## C

**carrier gas.** A gas conveying powder in the spray process from the powder feeder through the surfacing gun. See also **spray feedstock driving gas**.

**cascade sequence.** A combined longitudinal and cross sectional sequence in which spray deposits are made in overlapping layers. See Figure 1(b). See also **block sequence**, **continuous sequence**, and **cross-sectional sequence**.

**cathodic protection.** A technique to reduce the corrosion rate of a metal by making it the cathode of an electrochemical cell.

**cavitation erosion.** The progressive loss of material from a solid surface due to the collapse of bubbles or cavities within a liquid containing a gas, vapor, or a mixture of the two.

**ceramic.** A class of inorganic nonmetallic materials subjected to high temperatures during manufacture.

**cermet powders.** A blended or composite powder of metal and ceramic constituents.

**cladding.** A surfacing variation depositing or applying surfacing material, usually to improve corrosion or heat resistance. See also **buildup**, **buttering**, and **hardfacing**.

coating. A nonstandard term when used for **spray deposit** or **thermal spray deposit**.

coating density. A nonstandard term when used for **spray deposit density ratio**.

coating strength. A nonstandard term when used for **spray deposit strength**.

**cold gas-dynamic spray (CGSP).** A solid-state spraying process using a supersonic jet of compressed gas to accelerate near-room-temperature spray feedstock particles through a nozzle at very high velocities towards a substrate where they plastically deform and consolidate on impact. See **high-pressure cold gas-dynamic spray**, **low-pressure cold gas-dynamic spray** and **pulsed cold gas-dynamic spray**.

**cold spray.** See **cold gas-dynamic spray**. See also **high-pressure cold gas-dynamic spray**, **low-pressure cold gas-dynamic spray** and **pulsed cold gas-dynamic spray**.

**composite.** A material consisting of two or more discrete materials with each material retaining its physicochemical identity.

**composite powder.** See **powder composite**.

**composite spray deposit.** A spray deposit made with two or more dissimilar surfacing materials, which may be formed in layers.

**compressed layer.** A high-pressure high-density gas layer formed between the substrate surface and the bow shock creating a resistance to flow. See Figure 2. See also **bow shock** and **free jet**.

**compressed layer temperature.** See **flow stagnation temperature**.

**conformal spray deposit.** A spray deposit covering and fitting the shape of the substrate.

**conglomerated powder.** A substance of particles of different materials. See also **agglomerated powder** and **flocculated powder**.

**continuous sequence.** A longitudinal sequence in which each spray deposit pass is made continuously from one end of the substrate to the other. See also **block sequence**, **cascade sequence**, and **cross-sectional sequence**.

**continuous spray deposit.** A spray deposit made without interruption.

**convergent-divergent nozzle.** See **de Laval nozzle**.

**corrosion.** Chemical or electrochemical reaction between a material and its environment which results in deterioration in the properties of the material.

**cosmetic spray deposit bead.** A spray deposit bead used to enhance appearance.

**cosmetic spray deposit pass.** A spray deposit pass resulting in a cosmetic spray deposit bead.

**covalent bond.** A primary bond arising from the reduction in energy associated with overlapping half-filled orbitals of two atoms. See also **bonding force**, **ionic bond**, **mechanical bond**, and **metallic bond**.

**cover bead.** A spray deposit bead resulting from a cover pass.

**cover pass.** A spray deposit pass or passes resulting in the exposed layer of a multipass spray deposit on the side from which spraying was done.

**crack.** A fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement.

**crater.** Substrate surface discontinuity caused by mechanical impact such as a particle impacting at less than the critical velocity.

**critical spray angle.** The orientation of spray jet impingement at which the angle of incidence is sufficient to facilitate spray deposition.

**critical spray velocity.** The temperature-dependant (particle and substrate) spray velocity above which there is a transition from erosion to coating formation.

**cross-sectional sequence.** The order in which the passes of a multiple-pass spray process are deposited. See also **block sequence**, **cascade sequence**, and **continuous sequence**.

**crushed powder.** Powder formed from a solid which is crushed to the appropriate size for spraying. See also **milled powder**.

## D

**debond.** An interface separation of a coating from a substrate. See also **delamination**.

**defect.** A discontinuity or discontinuities that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. The term designates rejectability. See also **discontinuity** and **flaw**.

|| **degreasing.** The removal of grease and oil from a surface.

**delamination.** The separation of a coating into constituent layers. See also **debond**.

**de Laval nozzle.** A nozzle which converges to a throat and then diverges to allow gas expansion and produce gas acceleration.

delay time. A nonstandard term when used for **deposition delay**.

| **demixing.** The act of segregating a powder mixture, sometimes due to overmixing. See also **segregation**.

deposit. A nonstandard term when used for **spray deposit**.

**deposition.** The process of applying a sprayed material to a substrate.

|| **deposition delay.** The time interval from initiation of surface treatment by the flow of particles to the beginning of particle attachment to the substrate.

**deposition efficiency.** See **spraying deposition efficiency**.

**deposition rate.** The weight of material deposited in a unit of time. Usually expressed as kilograms per hour (kg/h) or pounds per hour [lb/h].

deposition sequence. A nonstandard term when used for **spray deposit pass sequence**.

deposit sequence. A nonstandard term when used for **spray deposit pass sequence**.

**discontinuity.** An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect. See also **defect** and **flaw**.

**dovetailing.** A method of surface preparation involving angular undercutting to interlock the spray deposit. See also **groove roughening**, **knurling**, **rotary roughening**, and **rough threading**.

driving gas. See **spray feedstock driving gas**.

**ductility.** The ability of a material to deform plastically without fracturing.

**duplex coating.** A coating consisting of two layers of two dissimilar materials.

**dust.** Fine dry pulverized particles. See also **particle** and **powder**.

dynamic spray. A nonstandard term when used for **cold gas-dynamic spray**.

## E

**edge loss.** Spray deposit lost as overspray beyond the edge of the substrate.

**elasticity.** The property of certain materials enabling them to return to their original dimensions after an applied stress.

**electromagnetic pulse spray.** A solid-state spraying process using electromagnetic force to propel spray feedstock particles through a nozzle at very high velocities towards a substrate where the particles plastically deform and consolidate on impact. See Figure 6. See also **cold gas-dynamic spray**.

**embrittlement.** The severe loss of ductility, toughness, or both, of a material usually a metal or alloy.

**erosion.** Removal of material from a surface due to mechanical interaction between the surface and a fluid, a multicomponent fluid, or impinging liquid or solid particles.

**erosion-corrosion.** Associated action involving corrosion and erosion in the presence of a corrosive substance.

**etch.** To erode a material surface by chemical, electrochemical, or mechanical means to highlight microstructure or create a pattern.

**exfoliation.** Corrosion proceeding laterally from the sites of initiation along planes parallel to the surface, generally at grain boundaries or coating interfaces, forming corrosion products that

force metal or coating away from the body of the material, giving rise to a layered appearance.

**exhaust booth.** A system of individual units functioning collectively to gather expended spray gases and airborne materials while simultaneously flushing and renewing the air in the working environment. See also **spray chamber** and **spraying booth**.

## F

**fatigue.** A cumulative effect causing a material to fail after repeated applications of stress none of which exceeds the ultimate tensile strength.

**fatigue strength.** The maximum cyclic stress a material can withstand for a specified number cycles before failure occurs.

**fatigue wear.** Wear of a solid surface caused by fracture arising from fatigue in the material.

feeder. See **powder feeder**.

**feed hopper.** A container used for holding and metering spray feedstock for delivery to the spray device. See also **powder feeder**.

**feed hopper pressure.** See **stagnation pressure**.

**feed rate.** The rate at which material passes through the spray device in a given length of time.

feedstock. A nonstandard term when used for **spray feedstock**.

**field spray deposit.** A spray deposit made at a location other than a shop or the place of substrate fabrication.

fill bead. A nonstandard term when used for **intermediate spray deposit bead**.

fill pass. A nonstandard term when used for **intermediate spray deposit pass**.

**filler.** A material added to a product to increase its bulk, weight, viscosity, opacity, strength, or simply to dilute it for economy.

filler bead. A nonstandard term when used for **intermediate spray deposit bead**.

filler pass. A nonstandard term when used for **intermediate spray deposit pass**.

**finer.** The portion of a powder composed of particles which are smaller than the specified size.

**finish allowance.** The amount of excess coating left on the surface for subsequent machining.

**fixture.** A device for holding workpieces in proper relation to each other.

**flaw.** An undesirable discontinuity. See also **defect** and **discontinuity**.

**flocculated powder.** Small lumps or loose clusters of loosely aggregated particles. See also **agglomerated powder** and **conglomerated powder**.

**flow rate.** The time required for a material of standard weight or volume to flow through an orifice according to a specific procedure.

**flow stagnation temperature.** Temperature of the fluid flow at the compressed layer. See also **room stagnation temperature** and **stagnation temperature**.

**fluidized bed.** A contained mass of finely divided solids behaving like a fluid when brought into suspension by a moving gas or liquid.

**free jet.** The jet of spray feedstock-laden carrier gas from the exit of the nozzle to the bow shock. See Figure 2. See also **bow shock** and **compressed layer**.

**fretting wear.** Material loss resulting from a small amplitude oscillatory motion between two solid surfaces in contact.

**fused and crushed powder.** Powder formed from a fused solid mass subsequently crushed to the appropriate size for spraying.

**fused coatings.** A process in which the coating material is deposited by spraying and then fused by post heat treatment. This can be done by flame, furnace, induction, laser, or resistance heating.

## G

**galvanic corrosion.** Accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.

**gas-dynamic spraying.** See **cold gas-dynamic spraying**.

**gas flow rate.** The flow rate of gas, typically in liters per minute (lpm) [standard cubic feet per minute (scfm)], through the spraying torch.

**graded coating.** A sprayed deposit composed of mixed materials in successive layers, progressively changing in composition from the material immediately adjacent to the substrate to that at the surface of the sprayed deposit.

gradient coating. A nonstandard term when used for **graded coating**.

graduated coating. A nonstandard term when used for **graded coating**.

**grain.** An individual crystal in a polycrystalline material.

**grain boundary.** A narrow zone corresponding to the transition from one crystallographic orientation to another, thus separating one grain from another.

**granular powder.** A finely divided material having approximately equidimensional but nonspherical, irregular shaped powders.



**grit.** Crushed ferrous or non-metallic abrasive material in various mesh sizes used in abrasive blasting to clean and/or roughen surfaces.

**grit blasting.** A process using a pressurized stream of grit to clean and roughen surfaces.

**groove roughening.** A method of surface preparation in which grooves are made and the original surface is roughened and spread. See also **dovetailing**, **knurling**, **rotary roughening**, and **rough threading**.

gun. A nonstandard term when used for **surfacing gun**.

## H

**hardfacing.** The application of a cladding or coating of material designed to resist wear. See also **buildup**, **buttering**, and **cladding**.

**hardness test.** A test designed to assess the resistance to penetration from a load. The surface is indented under a defined load and the depth or area of penetration is measured. See also **macrohardness** and **microhardness**.

hard surfacing. A nonstandard term for **hardfacing**.

**helmet.** See **blast helmet**.

**heterogeneity.** The quality or state of being heterogeneous.

**heterogeneous.** Made up of parts or elements, not unified, compatible, or proportionate. See also **homogeneous**.

**high pressure.** In cold gas-dynamic spray typically taken to mean the range of 2.5 MPa to 4 MPa [350 psi to 600 psi].

**high-pressure cold gas-dynamic spray (CGSP-H).** A cold gas-dynamic spray process variation employing high-pressure carrier gas and spray feedstock injection before the nozzle throat. See Figure 3. See also **low-pressure cold gas-dynamic spray** and **pulsed cold gas-dynamic spray**.

**homogeneity.** The quality or state of being homogeneous.

**homogeneous.** Of uniform structure or composition throughout. See also **heterogeneous**.

hood. A nonstandard term when used for **blast hood**.

**hydrogen embrittlement.** Hydrogen-induced cracking or severe loss of ductility caused by the presence of hydrogen in the metal matrix.

**hydrophilic.** Tending to absorb water.

**hydrophobic.** Tending to repel water or lacking affinity for water.



**hypersonic.** Having a Mach number of greater than 5.0. Some energy of the object goes into exciting the chemical bonds of the fluid. See also **subsonic** and **supersonic**.

## I

**impingement.** A continuing succession of impacts between a liquid or solid particles and a solid surface.

impingement angle. A nonstandard term when used for **spray angle**.

**impingement corrosion.** A form of erosion-corrosion generally associated with the impingement of a high velocity, flowing liquid containing air bubbles against a solid surface.

impingement zone. A nonstandard term when used for **compressed layer**.

**impregnation.** A process of filling the pores of a material with sealant.

**impurity.** An unwanted minor constituent or one of an unacceptable concentration level. See also **inclusion**.

**incident particles.** Those particles transferring most of their potential energy to the substrate. See also **reflected particles**.

**inclusion.** Entrapped foreign solid material or a physical discontinuity within a material.

**induction time.** See **deposition delay**.

**inert gas.** A stable gas that does not support combustion and does not form reaction products with other materials. Included are helium, argon, and sometimes nitrogen.

injection angle. See **spray feedstock injection angle**.

**interconnected porosity.** A network of pores in and extending to the surface of a coating.

**intergranular corrosion.** Corrosion occurring preferentially at grain boundaries.

**intermediate spray deposit bead.** The spray deposit resulting from an intermediate spray deposit pass.

**intermediate spray deposit pass.** A spray deposit pass within a cross-sectional sequence lying between the first spray coating pass or layer and the cover pass or layer.

**internal energy.** The sum of an objects kinetic and potential energies. See also **kinetic energy** and **potential energy**.

**internal oxidation.** The formation of isolated particles of corrosion products beneath the surface of the metal or coating as a result of preferential oxidation of certain alloy constituents.

**ionic bond.** A primary bond arising from the electrostatic attraction between two oppositely charged ions. See also **bonding force**, **covalent bond**, **mechanical bond**, and **metallic bond**.

**irregular powder.** Finely divided particles lacking symmetry. See also **nodular powder**.

## J

**jet.** A forceful stream of fluid discharged from a narrow opening or a nozzle.

## K

**kinetic energy.** The energy a substance possesses by virtue of its velocity of motion. See also **internal energy** and **potential energy**.

**kinetic spray.** A nonstandard term when used for the **cold gas-dynamic spray** process.

**knurling.** A method of surface preparation in which the surface is upset with a knurling tool. See also **dovetailing**, **groove roughening**, **rotary roughening**, and **rough threading**.

## L

**laval nozzle.** See **de Laval nozzle**.

**layer.** A stratum of spray deposit consisting of one or more spray deposit beads.

**linear discontinuity.** A discontinuity with a length substantially greater than its width.

**localized corrosion.** Corrosion at discrete sites, for example, pitting, crevice corrosion, and stress corrosion cracking.

**low pressure.** In cold gas-dynamic spray typically taken to mean the range of 0.5 MPa to 1 MPa [70 psi to 145 psi]

**low-pressure cold gas-dynamic spray (CGSP-L).** A cold gas-dynamic spray process variation employing low-pressure carrier gas and spray feedstock injection after the nozzle throat. See Figure 4. See also **high-pressure cold gas-dynamic spray** and **pulsed cold gas-dynamic spray**.

**lubricant.** Any substance interposed between two surfaces for the purpose of reducing the friction or wear between them.

## M

**Mach number.** The speed of an object relative to a fluid medium divided by the speed of sound in the medium. See also **hypersonic**, **subsonic**, and **supersonic**.

**macrograph.** A graphic reproduction of the image of an object as seen by the naked eye.

**macrohardness.** The result of a hardness test performed on a macroscopic scale to show the bulk property of a material. See also **microhardness**.

**manual spraying.** A spraying operation with the surfacing gun held and manipulated by hand. Accessory equipment, such as part motion devices may be used. See also **automatic spraying, mechanized spraying, robotic spraying** and **semiautomatic spraying**.

**mask.** A material or device used to conceal or screen from a process.

**matrix.** The continuous phase of a material or coating in which separate particles of another constituent are embedded.

**maximum substrate velocity.** The substrate velocity above which substrate activation is insufficient to facilitate particle attachment. See also **substrate velocity**.

**mean particle size.** The equivalent average spherical particle size. See also **particle size**.

**mechanical bond.** The adherence by interlocking such as a spray deposit to a roughened surface. See also **bonding force, covalent bond, ionic bond, and metallic bond**.

**mechanized spraying.** An operation with equipment requiring manual adjustment by an operator in response to visual observation, with the surfacing gun held by a mechanical device. See also **automatic spraying, manual spraying, robotic spraying, and semiautomatic spraying**.

**mesh size.** The designated openings in a sieve or screen. See also **minus sieve** and **plus sieve**.

US Sieve Size	Tyler Equivalent	Opening	
		mm	in
No. 120	115 Mesh	0.125	0.0049
No. 140	150 Mesh	0.105	0.0041
No. 170	170 Mesh	0.088	0.0035
No. 200	200 Mesh	0.074	0.0029
No. 230	250 Mesh	0.063	0.0025
No. 270	270 Mesh	0.053	0.0021
No. 325	325 Mesh	0.044	0.0017
No. 400	400 Mesh	0.037	0.0015

**metal.** An opaque, lustrous, elemental chemical substance that is a good conductor of heat and electricity, usually malleable, ductile, and more dense than other elemental substances.

**metallic bond.** The primary bond holding metals together arising from the increased spacing of valence electrons when an aggregate of metal atoms are in close proximity. See also **bonding force, covalent bond, ionic bond, and mechanical bond**.

**metallizing.** A nonstandard term when used for **spraying** or the application of a metal spray deposit.

**metal-matrix composite.** A material with nonmetallic reinforcement incorporated in the metallic matrix. The reinforcement may constitute from 10% to 60% of the material. Example reinforcements include graphite, silicon carbide, and refractory metals.

**micrograph.** A graphic reproduction of the image of an object formed by a microscope.

**microhardness.** The result of a hardness test performed on a microscopic scale to determine the property of individual phases within a material and avoid the effects of porosity. See also **macrohardness**.

**microinch.** One millionth of an inch (0.000001 in) [.0000254 mm].

**micrometer ( $\mu\text{m}$ ).** One millionth of a meter (0.001 mm) [0.0003937 in].

**micron.** See **micrometer**.

**microtrack.** A device for measuring powder particle size distributions.

**mil.** One thousandth of an inch (0.001 in) [0.0254 mm].

**milled powder.** Powder or powder mixtures having received the mechanical treatment, such as by ball milling, to alter the size or shape of the individual particles or to coat one component of the mixture with another. See also **crushed powder**.

**minus sieve.** The portion of a powder sample passing through a standard sieve of specified mesh size. See also **plus sieve**.

**mixed powder.** Thoroughly intermingled powder of different materials. See also **blended powder**.

## N

**nanostuctured powder.** Particles displaying grains or phases whose average size is less than 200 nm.

**nodular powder.** Finely divided particles having a regular shape. See also **irregular powder**.

**nozzle.** See **spray nozzle**.

**nozzle accumulation.** Filler metal or surfacing material deposited on the inner surface and on the exit end of the nozzle.

## O

**orifice.** The portion of the nozzle containing the throat.

**orifice throat length.** The length of the constricting orifice.

**overspray.** The portion of the spray feedstock not deposited on the substrate.

**oxidation.** Loss of electrons by a constituent of a chemical reaction, or the corrosion of a metal exposed to an oxidizing gas at elevated temperatures.

**oxidizing.** An environment or material promoting oxidation.

## P

**particle.** The smallest discrete portion of a powder. See also **dust** and **powder**.

**particle shape.** The appearance of any particle. Common shapes include spherical, rounded, angular, acicular, dendritic, irregular, porous, fragmented, blocky, rod, flake, nodular, or plate. See Figure 7.

**particle size.** The controlling lineal dimension of an individual particle as determined by analysis with sieves or other suitable means. See also **mean particle size**.

**particle size distribution.** The percentage by weight or by number of each particle size in the powder sample.

**particle volume concentration.** The ratio of particle volume to carrier gas volume in the surfacing spray. Usually expressed in  $m^3/m^3$ .

**pass.** See **spraying pass**.

**pass sequence.** See **cross-sectional sequence**.

**passivation.** The process in metal corrosion by which metals become passive.

**passive.** The state of a metal surface characterized by low corrosion rates in a potential region strongly oxidizing for the metal.

**peening, blasting.** Blasting process using shot or spherical shaped beads, for cleaning and/or modifying surface properties.

**peening, mechanical.** The mechanical working of metals using impact blows.

**permeability.** The rate of passage of a liquid or gas through a solid material.

**pitting.** Small localized cavities caused by corrosion, wear, or other mechanically assisted degradation of a surface.

**plastic deformation.** The permanent distortion of solid materials under applied stresses straining the material beyond its elastic limit.

**plus sieve.** The portion of a powder sample retained on a sieve of specified mesh size. See also **minus sieve**.

**polishing.** The smoothing of a material surface by means of the action of abrasive particles attached usually to a fabric cloth.

**pore.** A small opening, void, or channel within a solid. See also **pull-out**.

**pore size.** The largest dimension of a pore.

**porosity.** The presence of pores, usually expressed as a percentage by volume.

**potential energy.** The stored energy a substance possesses because of its position or arrangement of its parts. See also **internal energy** and **kinetic energy**.

**powder.** A material manufactured into finely divided particles. See **spray feedstock**. See also **dust** and **particle**.

**powder alloy.** A powder prepared from a homogeneous molten mixture of elements. See also **powder blend** and **powder composite**.

**powder blend.** A powder mixture of two or more alloy powders. See also **powder alloy** and **powder composite**.

**powder composite.** A powder in which each particle consists of two or more distinct materials joined together as by chemical cladding, mechanical agglomeration, or by spray drying. See also **powder alloy** and **powder blend**.

**powder constituent.** The various components of the powder mixture.

**powder feeder.** A mechanical device designed to introduce a controlled flow of powder to the spray device. See also **feed hopper**.

**powder injection angle.** See **spray feedstock injection angle**.

**powder port.** See **spray feedstock port**.

**pre-alloyed powder.** A powder composed of two or more elements alloyed in the powder manufacturing process and in which the particles are of the same nominal composition throughout.

**preheat.** The heat applied to the substrate to remove moisture, minimize thermal shock effects, improve deposition efficiency, or enhance bond strength.

**procedure.** The detailed elements of a process or method used to produce a specific result.

**process.** A grouping of basic operational elements.

**protective atmosphere.** A gas or vacuum envelope present during joining, thermal cutting, or thermal spraying, used to prevent or reduce the formation of oxides and other detrimental surface substances, and to facilitate their removal.

**pull-out.** A surface discontinuity where particles are forcibly extracted from the coating surface during finishing. See also **pore**.

**pulsed cold gas-dynamic spray (CGSP-P).** A cold gas-dynamic spray process variation employing a shutter to generate high-pressure carrier gas shock waves to propel spray feedstock through a nozzle. See Figure 5. See also **high-pressure cold gas-dynamic spray** and **low-pressure cold gas-dynamic spray**.

**purge.** The introduction of a gas to remove contaminants from a system.

## R

**rate of deposition.** See **deposition rate**.

**reducing atmosphere.** A type of protective atmosphere dissociating metal oxides at elevated temperatures.

**reflected particles.** Those particles not reaching the critical velocity of the spray feedstock or are deflected to a spray path less than the critical spray angle. See also **incident particles**.

**residual stress.** Stress present in a material free of external forces or thermal gradients.

**robotic spraying.** A spraying operation with equipment moving along a controlled path using controlled parameters with no manual intervention once a cycle is initiated. See also **automatic spraying, manual spraying, mechanized spraying, and semiautomatic spraying**.

**room stagnation temperature.** The ambient temperature of the spray chamber. See also **flow stagnation temperature** and **stagnation temperature**.

**rotary roughening.** A method of surface preparation in which a revolving tool is pressed against the surface being prepared, while either the work or the tool, or both, move. See also **dovetailing, groove roughening, knurling, and rough threading**.

**rough threading.** A method of surface roughening consisting of cutting threads with the sides and tops of the threads jagged and torn. See also **dovetailing, groove roughening, knurling, and rotary roughening**.

## S

**sacrificial coating.** A coating providing corrosion protection wherein the coating material corrodes in preference to the substrate.

**sand.** A granular material resulting from the disintegration or crushing of rocks or minerals.

**sandblasting.** Abrasive blasting with sand.

**scale.** Loosely adherent layers of corrosion products resulting from surface oxidation.

**scoring.** A severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding.

**scratching.** The mechanical removal, displacement, or both, of material from a surface by the action of abrasive particles or protuberances sliding across the surface.

**seal coat.** Material applied to infiltrate and close the pores of a spray deposit.

**sealant.** A preparation of resin or wax type materials for sealing the porosity in coatings.

**sealer.** See **sealant**.

**sealing.** A process which increases the resistance to corrosion of the underlying substrate material.

**segregation, powder.** Separation of powder particles by size, shape, or composition. See also **demixing**.

**semiautomatic spraying.** A spraying operation performed manually with equipment controlling one or more of the process conditions. See also **automatic spraying, manual spraying, mechanized spraying,** and **robotic spraying**.

**shadow mask.** A spraying technique in which an area is partially shielded during spraying thus permitting a feathering of the spray deposit at the coating edge. A common technique is to raise the mask above the substrate.

**shielding gas.** A gas used to produce a protective atmosphere.

**shock wave.** A propagation disturbance within a solid, liquid, or gas medium across which there is a finite decrease in velocity and large and abrupt rise in pressure, temperature, and density of the flow. See also **bow shock**.

**shot peening.** The bombardment of a component surface with steel or ceramic shot to produce a residual compressive stress in the surface and improve fatigue and stress corrosion performance.

**shrinkage.** A decrease in dimensions of a coating during processing.

**shrinkage stress.** A nonstandard term when used for **residual stress**.

**sieve classification.** Portion of a powder sample passing through a standard sieve of a specified number and retained by some finer sieve of a specified number.

**size analysis.** Analysis of the size of the particles being deposited by spraying processes.

**size distribution.** The distribution of sizes within a size analysis. The distribution may be normal or skewed in some way due to the powder manufacturing process.

**smoothing bead.** A spray deposit bead made to correct an undesirable spray deposit surface contour. See also **cosmetic spray deposit bead**.

**smoothing pass.** A spray deposit pass resulting in a smoothing bead. See also **cosmetic spray deposit pass**.



**solid-state spraying.** A group of spray processes applying surfacing materials without melting.  
See also **cold gas-dynamic spray** and **electromagnetic powder spray**.

**spalling.** The chipping, fragmentation, or separation of a surface.

**splat.** A single thin flattened sprayed particle.

**spray.** A jet of vapor or finely divided liquid.

**spray, v.** The act of spraying.

**spray angle.** The angle of particle impingement on the substrate. See also **critical spray angle**.

spray booth. A nonstandard term when used for **spraying booth**.

**spray chamber.** An enclosed space in which the spraying process is confined. See also **exhaust booth** and **spraying booth**.

**spray chamber temperature.** See **room stagnation temperature**.

**spray deposit.** The substrate coating or layer of surfacing material applied to a substrate.

**spray deposit bead.** A spray deposit resulting from a spraying pass.

**spray deposit density ratio.** The ratio, usually expressed as a percentage, of the determined density to the theoretical density of the coating material. See also **determined density** and **theoretical coating**.

**spray deposit interface.** The boundary between the spray deposit and the substrate.

**spray deposit pass sequence.** The order in which the surfacing gun is manipulated relative to the substrate to apply the desired spray deposit. See **block sequence**, **cascade sequence**, **continuous sequence**, and **cross-sectional sequence**.

**spray deposit strength.** A measure, usually expressed in kPa (psi), of the cohesive bonding within a spray deposit. See also **adhesive strength**.

**spray distance.** The distance maintained between the surfacing gun nozzle tip and the substrate surface. See Figure 2.

**spray feedstock.** Any consumable form of spray material used in the application of a coating.

**spray feedstock driving gas.** A pressurized gas applied to the spray feedstock to facilitate its flow into the surfacing gun.

**spray feedstock injection angle.** The angular measurement between the carrier gas axis and the axis of spray feedstock introduction.

**spray feedstock port.** The aperture through which powder is introduced into the spraying apparatus.

**spray force.** The axial force developed by a spray jet.

**spray forming.** The fabrication of free standing shapes by the deposition of material onto a substrate.

spray gun. A nonstandard term when used for **surfacing gun**.

|| **spray nozzle.** Portion of the spray device through which the spray is shaped and projected.

|| **spray surfacing.** A group of surfacing processes applying material to a substrate by spraying. See also **solid-state spraying** and **thermal spraying**.

**sprayer.** One who performs semiautomatic spraying. See also **spraying operator**.

**spraying booth.** An exhaust booth where spray surfacing is performed. See also **exhaust booth** and **spray chamber**.

**spraying deposition efficiency.** The ratio, usually expressed in percent, of the weight of spray deposit to the weight of the material sprayed.

spraying induction time. A nonstandard term when used for **deposition delay**.

**spraying operator.** One who operates automatic, mechanized, or robotic spray surfacing equipment. See also **sprayer**.

|| **spraying pass.** A single progression of the surfacing gun across the substrate surface resulting in a spray deposit bead or layer.

spraying pass sequence. A nonstandard term when used for **spray deposit pass sequence**.

**spraying sequence.** The order in which layers of materials are applied in a planned relationship such as overlapped, superimposed, or at various angles. See also **spray deposit pass sequence**.

**stagnation point.** The point at which the fluid flow comes to rest and kinetic energy is converted into internal energy.

| **stagnation pressure.** The pressure a gas would exhibit if brought to zero velocity by an isentropic process. Generally used to refer to the fluid pressure in the pre-chamber.

**stagnation temperature.** Temperature of the fluid flow at the stagnation point. See also **flow stagnation temperature** and **room stagnation temperature**.

stand-off distance. A nonstandard term when used for **spray distance**.

**strain.** A measure of the extent to which a body is deformed when it is subjected to a stress.

|| **stress.** The force per unit area on body tending to cause it to deform. It is a measure of the internal forces in a body between particles of the material of which it consists as they resist separation, compression, or sliding.

**stress corrosion cracking.** A cracking process requiring the simultaneous action of a corrosive and sustained tensile stress.

**subsonic.** Having a Mach number of less than 1.0. See also **supersonic** and **hypersonic**.

**substrate.** The parent or base material to which the coating is applied.

**substrate activation.** Cleaning and roughening of the substrate surface due to particle impingement.

**substrate velocity.** The speed of the substrate relative to a stationary spray nozzle. See also **maximum substrate velocity**.

**supersonic.** Having a Mach number of greater than 1.0. High supersonic speeds are those between 3 and 5. See also **subsonic** and **hypersonic**.

**surface preparation.** Cleaning and roughening of the surface to be sprayed to improve the adhesion of the coating to the substrate.

**surface roughening.** A group of methods for producing irregularities on a surface. See also **dovetailing, groove roughening, knurling, rotary roughening, and rough threading**.

**surface topography.** The geometrical detail of a surface, relating particularly to microscopic variations in height.

**surface void.** A void which is located at the surface of a coating.

**surfacing.** The application by welding, brazing, or spray surfacing of a layer, or layers, of material to a surface to obtain desired properties or dimensions, as opposed to making a joint. See also **buildup, buttering, cladding, and hardfacing**.

**surfacing gun.** A device used to apply energy to spray feedstock and direct the resulting surfacing spray towards a substrate.

**surfacing material.** The material applied to a base metal or substrate during surfacing. See also **surfacing metal**.

**surfacing metal.** The metal or alloy applied to a base metal or substrate during surfacing. See also **surfacing material**.

**surfacing spray.** The jet of surfacing material and any corresponding carrier fluid.

## T

**tensile strength.** A measure of the resistance a material offers to tensile stress. It is defined as the stress required to break the material, and expressed as the force per unit cross sectional area.

**tensile stress.** Axial forces per unit area applied to a body tending to extend it.

**theoretical density.** The density of a solid homogeneous piece of material.

**thermal barrier coating.** A coating forming an insulating barrier to a heat source to protect the substrate.

**thermal spray deposit.** A spray deposit created with a thermal spray process.

**thermal spraying (THSP).** A group of processes in which finely divided metallic or nonmetallic surfacing materials are deposited in a molten or semimolten condition on a substrate to form a thermal spray deposit. The surfacing material may be in the form of powder, rod, cord, or wire.

**throat.** The point or region in the fluid flow passage having the minimum cross-sectional area.

**tribology.** The science and technology concerned with interacting surfaces in relative motion.

**two-phase flow.** A flow consisting of two different phases of material, for example of both gas and solid phases.

## U

**undercoat.** A deposited coat of material acting as a substrate for a subsequent spray deposit.

**undercutting.** A surface preparation step involving the removal of substrate material.

## V

**vacuum cold spray.** A nonstandard term when used to describe execution of the cold gas-dynamic spray process in a vacuum environment.

**vapor.** The gaseous form of substances normally present in a solid or liquid state.

**venturi.** A region in a fluid flow passage where flow is constricted to increase the velocity of fluid. This region encompasses the tapering constriction, the throat, and the diverging section before the nozzle tube.

**virgin material.** A material not subjected to any processing other than its original manufacture.

**void.** A shrinkage cavity produced during spraying or solidification.

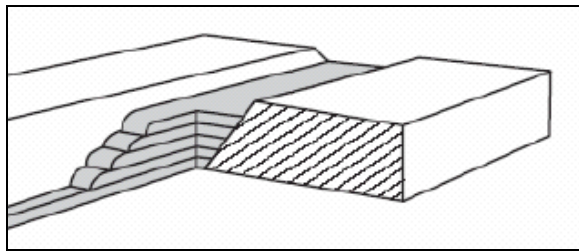
**void content.** The volume percentage of voids.

## W

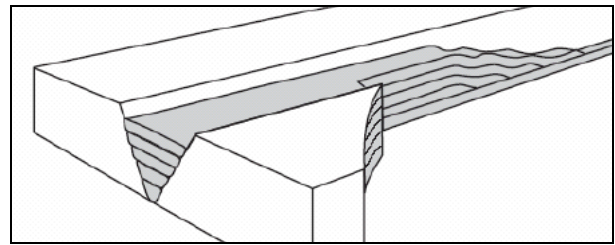
**wear.** Loss of material from a surface by means of some mechanical action. See also **abrasive wear**, **cavitation erosion**, **erosion**, **fatigue wear**, **fretting wear**, and **scoring**.

**workpiece.** An assembly, component, member, or part being altered by a manufacturing process.

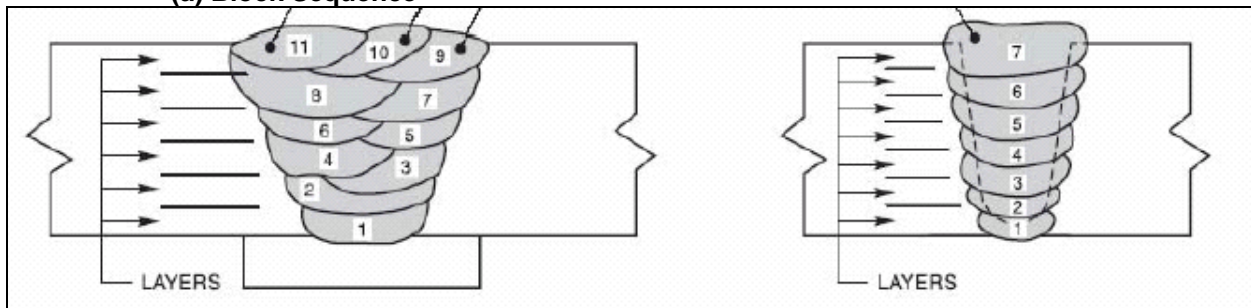
**Appendix A – FIGURES**



**(a) Block Sequence**

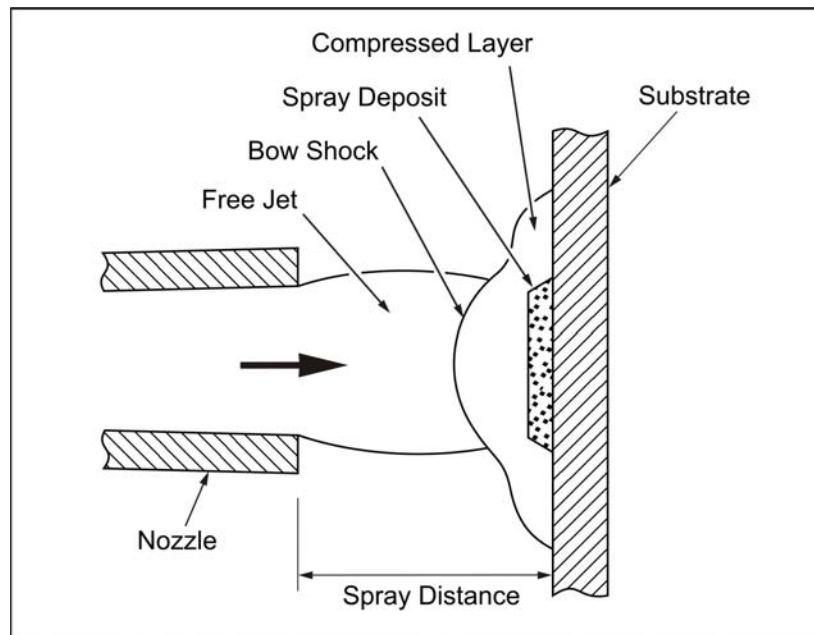


**(b) Cascade Sequence**

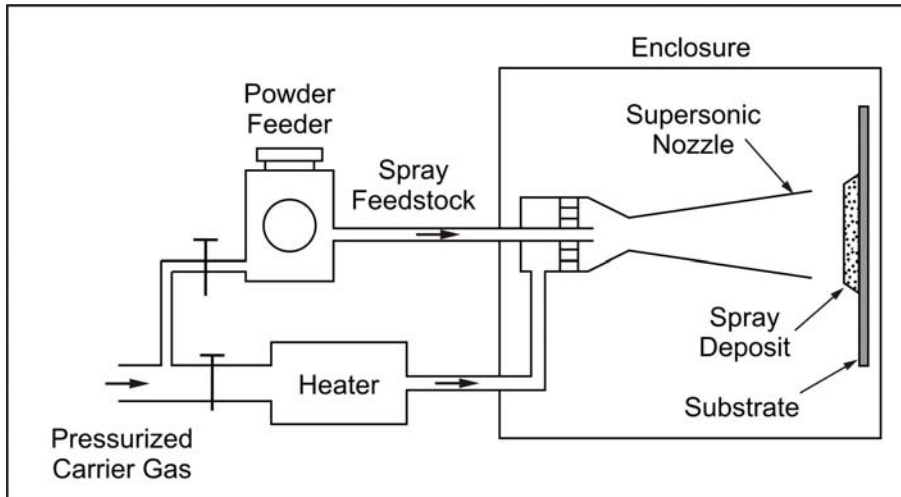


**(c) Cross-sectional Sequence**

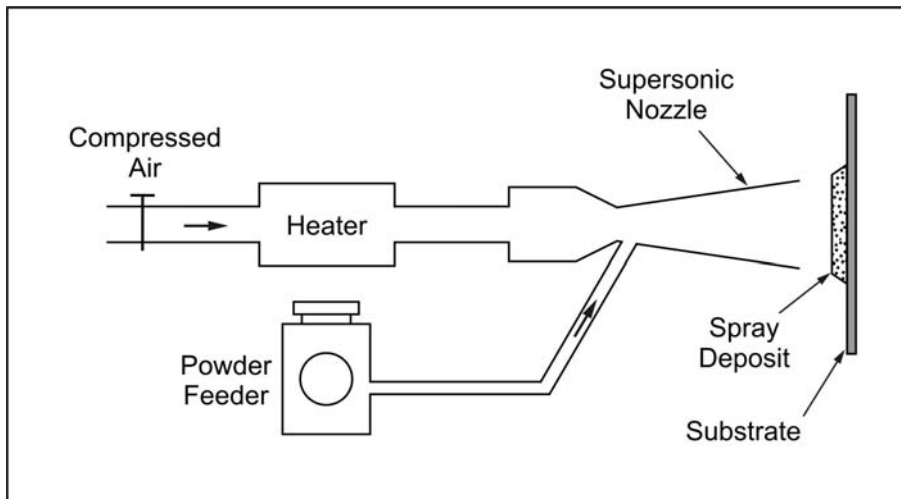
**Figure 1 – Multiple-pass Spray Deposition Sequences**



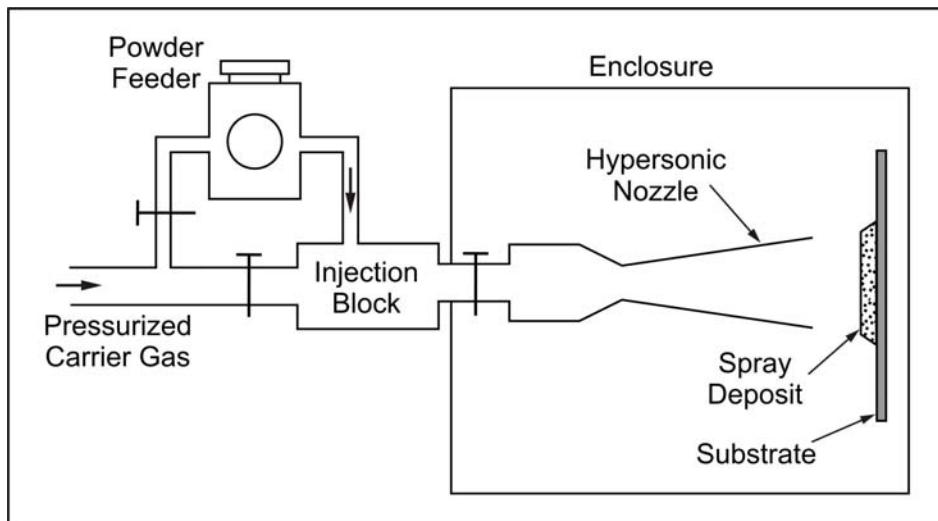
**Figure 2 – Spray Jet**



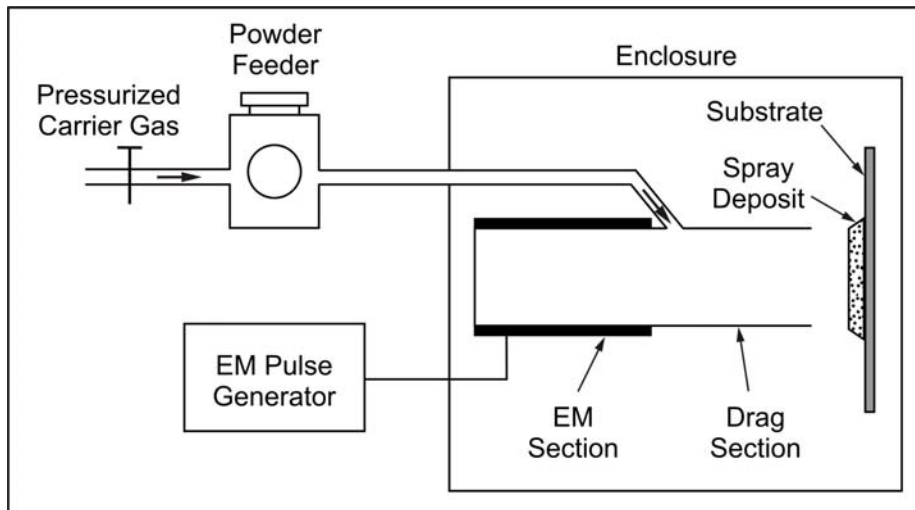
**Figure 3 – High-Pressure Cold Spray System Configuration**



**Figure 4 – Low-Pressure Cold Spray System Configuration**



**Figure 5 – Pulsed Cold Spray System Configuration**



**Figure 6 - Electromagnetic Pulsed Spray**

One-dimensional			
Acicular		Irregular Rod-like	
Two-dimensional			
Dendritic		Flake	
Three-dimensional			
Spherical		Rounded	
Irregular		Porous	
Angular			

**Figure 7 – Metal Particle Shapes**



## Appendix B – COMMENTARY

As stated in the Foreword and defined in the Scope, there has been no intentional act to exclude any process term from this document. To accomplish the objectives of the publication it is necessary to determine standard and nonstandard terms. As one might expect, not all of the choices made in the determination of the standard terms in this glossary have been universally accepted. This commentary is included to explain the reasons and logic behind the decisions with the hope it will lead to acceptance if not consensus.

### B1. Spray Surfacing

During implementation of the cold gas-dynamic spray process it has become apparent there is a need to make a clear distinction between the thermal and solid state spray processes. The early recognition of cold spray as a thermal spray process variation did not consider the need to clearly communicate unique requirements, especially those pertaining to health and safety. This distinction is necessary to ensure the codes, standards, policies, and procedures relating to the different process families do not become unnecessarily onerous for either.

The distinction also aides the users in understanding the cold gas-dynamic spray process has different process parameters enabling a new range of surfacing applications. Thermal spray and solid state spray processes are complimentary. Neither should be judged on the successes or failure of one another in a particular process application.

### B2. Cold Gas-Dynamic Spray

There is no question the term Cold Spray has and will continue to be associated with the process. The term Cold Spray in this document is identified as a synonym to the standard term Cold Gas-Dynamic Spray. However, the term Cold Spray has such a wide use in metallurgy and other fields of endeavor that it simply does not fulfill the need for a process designation. It is desirable to have a process designation that does not rely on establishing the context of application before the meaning of the term is clearly understood.

For this reason, a term was selected from the writings of pioneering and leading experts in the technology. The format of the term, specifically the placement of a hyphen is similarly derived. This term is unique, unambiguous, and employs words that communicate the nature of the process.

### B3. High-Pressure, Low-Pressure, and Pulsed Cold Gas-Dynamic Spray

It is difficult at the founding of a new technology to establish terms to act as a foundation throughout its anticipated refinement and evolution. It is never the less important to establish a base as soon as possible to facilitate continuity and inhibit the propagation of incongruent trade names as principal process references. There is obviously no impediment for anyone to use trade names or registered trademarks. However, the objective of this glossary is to make communication easier so there are minimal impediments to process understanding and ultimately process implementation.

The selected terms highlight pressure as the distinguishing characteristic for the principal process variations. This is somewhat arbitrary but it is congruent with common terminology. It also offers advantages over a distinction based on velocity, temperature, nozzle type, particle size, or perhaps spray feedstock introduction point. The pressure also serves to communicate an understanding of the basic system configuration and process requirements.

## Appendix C - PROCESS REFERENCES

The following process references are included to provide attribution for the wide variety of names associated with the Cold Gas-Dynamic Spray process. In many cases, the process terms listed have been assigned for marketing reasons and do not represent unique processes or process variations. The determination of equivalence to the standard process terms is left to the determination of the reader or to the individual or organization attributed to the term. Additions and corrections to the listing are welcomed.

**Cold Gas-Coating Technique** - RWTH Aachen University

**Cold Gas-Dynamic Method (CGDM)** – Papyrin

**Cold Gas-Dynamic Spray Technology** – Ktech Corporation

**Cold Gas-Dynamic Spray Method (CGSM)** – Advanced & Exploratory Systems  
Department of Sandia National Laboratories and University of New Mexico and ASB Industries, Inc.

**Cold Spray(TM)** - CRADA program consortium (2000-2003) formed by Sandia, ASB, Alcoa, Pratt&Whitney, Ktech, and Westinghouse

**Cold Spray Processing** - Ktech Corporation

**Dymet** - Obninsk Center for Powder Spraying (OCPS)

**Electromagnetic Powder Deposition (EPD)** -The University of Texas at Austin Center for Electromechanics (UT-CEM)

**Gas-Dynamic Spray (GDS)** - Obninsk Center for Powder Spraying (OCPS).

**Kinetic Metallization®** - Innovative Technology, Inc.

**Kinetic Spray Process** – Consortium organized under the auspices of the National Center for Manufacturing Sciences (NCMS). Members included: General Motors R&D Center; Flame-Spray Industries, Inc.; TubalCain Co.; Pratt and Whitney Division; GE Aircraft Engines; Ford Motor Co.; and, NCMS.

**Kinetic Spray Coating.** See **Kinetic Spray Process.**

**Kinetic Spray Coating Method** - Delphi Technologies, Inc.

**Supersonically Induced Mechanical Alloy Technology (SIMAT)** - Technologies Decision Management, Inc.

**Vacuum Cold-Spray (VCS)** – Xi'an Jiaotong University

## Appendix D – DOCUMENT REVISION HISTORY

Version	Revision	Change Comments †
1.0	5/30/2007	Initial Issue
1.1	6/08/2007	Various – from internal review prior to public disclosure
1.2	8/22/2007	Illustrations updated Revised process variation terms to include “Gas-Dynamic” Added: Appendix B (Commentary) and Appendix D (Revision History) Minor revisions to Appendix C based on comments received
1.3	10/01/2007	Reinforced difference between carrier gas and new term, spray feedstock driving gas. Clarified demixing by adding segregation. Expanded preheat.
1.4	10/28/2007	General editorial enhancements and corrections. Added process abbreviations to process chart and definitions. Added terms for fretting wear and cavitation erosion.

† Only the significant changes are listed here. As noted in the Scope, the document contains vertical bars to the left of the text which identify all of the changes from the prior version.