Recently Patented Facilities and Applications in Cold Spray Engineering

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Abstract: Currently available facilities in Cold Spray are limited in use because of some unwanted features. The first feature is powder feeding into working gas, possibly uniform heating and acceleration up to necessary temperature and velocity. The second is connected with a dilemma service term/cost of working nozzle production. Another problem is collection of un-deposited powder. It allows cost-effective production of articles by re-using the powder and prevents the environment pollution. For success marketing there is a need for new applications including those where Cold Spray that from can be embedded (build in) easily and cost-effective.

In the present paper, the most important patents published since the last 3 years and claiming the solutions of typical problems in convenient Cold Spray devices allowing increasing effectiveness and reducing the costs of both the device's units and products, prolong service term and searching new application areas are reviewed. Modernization has reached by material replacing, geometry, and embedding additional units into main design. Concerning new applications the patents cover the area connected with the production of corrosive, electrical/magnetic and other barrier coating articles.

Keywords: Cold Spray, coating, particles, prechamber, Laval nozzle, heater, powder feeder, expansion ratio.

INTRODUCTION

For best understanding of providing improvements in cold spray technique it is necessary to consider typical scheme of cold spray system (Fig. **1**).

Working gas of static pressure near 0.6-3.5 MPa is heated in gas heater up to temperature of 100-600°C. Powder from the powder feeder moves into the spray unit and is mixed with a working gas. Working gases can be: air, helium, argon, nitrogen, and their mixes. In the spray, unit powder is accelerated and heated by gas flow. After leaving the nozzle, particles interact with substrate and create a coating. Typical spray unit is shown in Fig. **2**.

Prechamber of the nozzle is designed as a unit for mixing working gas and low-velocity gas-powder mix, which moves from the powder feeder and entrances typically at the axis of prechamber. Prechamber, as a rule, have pipe-bends for measurement of gas pressure and gas temperature. Low-velocity gas-powder mixes entrances into prechamber after honeycomb-type collimator which ensures the strength of construction and alignment of flow. Low-velocity gas-Powder mixture moves from the feeder into prechamber under high pressure (value of static pressure in powder mix must be higher than pressure of working gas). That is why powder feeder must be designed considering high level of pressure inside. Prechamber is connected to Laval nozzle that has converging and diverging regions. Converging region of Laval nozzle typically has a conical shape diverging region has two types of shapes: conical shape (of round cross-section) and prismatic shape (of rectangular cross-section).

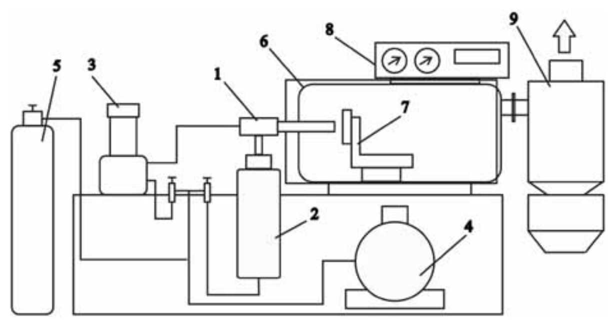

Fig. (1). Basic elements of cold spray system: 1 - spray unit composed of prechamber and supersonic nozzle; 2 - gas heater; 3 - powder feeder; 4 - compressor; 5 - gas container; 6 - spray tank; 7 - substrate;8 - control panel; 9 - powder separator.

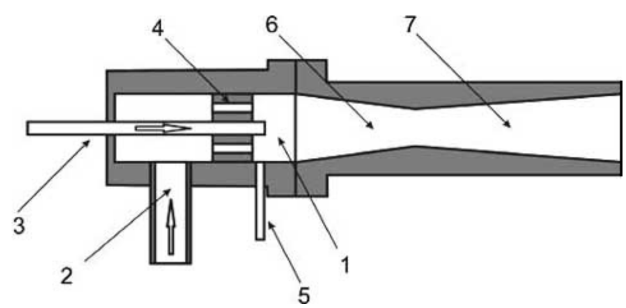

Fig. (2). Spray unit design: 1 - prechamber; 2 - main gas; 3 - powder mix; 4 - honeycomb-type collimator; 5 - control sensors; 6 - converging region; 7 - diverging region.

Distinguishing feature of cold spray nozzle design is high extension (ratio between length of supersonic (diver-ging) part of the nozzle and minimal size of exit cross-section). For

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example, typical minimal size of exit cross-section is of 2 - 5 mm and length of supersonic diverging region is of about 50 - 150 mm. Extension ratio is about 10 - 75 mm. This type of nozzle is difficult and costly in manufacturing. Expansion ratio (ratio between area of throat (critical) cross-section and area of exit cross-section) provides Mach number 1.5 - 3.5 of supersonic flow and high velocity of powder particles. Pressure inside prechamber depends mainly on working gas type, temperature, and expansion ratio and falls in the range 0.6 - 3.5 MPa.

For manufacturing cold spray nozzle machining of different kind of steels is often used with or without welding operation but sintering of ceramics is rare used.

It is necessary to say that "cold spray" technique and "kinetic spray" technique is based on the same physical phenomenon, which occurs during impact and interaction between high-velocity particles and substrate, both having temperature lower than melting point (e.g. [1]). In this regard "kinetic spray" and "cold spray" in present article are considered as techniques with similar parameters and characteristics. That is why the improvements in kinetic spray engineering are useful for the application in cold spray engineering.

Typical cold spray system allows producing coatings from plastic (ductile) material and alloys like copper, aluminum, zinc, nickel etc of thickness of 50 - 1000 μm and in some cases with more productivity (build up rate). Since the temperature is relatively low oxidation and other phases and structure transformations are avoided and coating inner properties does not change from powder particle inner properties. This is the main advantage of cold spray technique.

Exploiting of cold spray facilities shows high level reliability and validity. One way for improvement concerns powder feeding. Pressure inside feeder must be set higher than pressure inside prechamber. Pressure inside prechamber can achieve 3.5 MPa that leads to design of powder feeder to be relatively complex. Feeder bunker with powder must be closed hermetically during operation and holds the pressure. Problems arise these type of powder feeders are costly and change of powder material is time consuming. For changing powder material cold spray device must be switched off and pressure must be dropped down to ambient pressure.

Another way for improvements concerns nozzle service term. During exploitation nozzle walls are exposed by erosion when powder material used is harder than nozzle material and by deposition when powder material coats nozzle walls. These two contrary processes change nozzle geometry and gas and powder parameters (velocity and temperature) by unexpected manner in many cases. Eroded nozzle can be replaced only. Plugged nozzle can be repaired in some cases by mechanical machining, electric erosion technique, and chemical etching. These repair methods are limited by nozzle material and powder material, and their combination. For example, steel nozzle plugged by aluminum powder can be easily etched with aid of NaOH (but it takes time depending on the solution concentration and temperature up to several hours).

Another way for improvement concerns collection of unattached powder particles. After impingement on substrate, rejected gas and powder particles have relatively high velocities and in many cases unexpected tracks that prevent usage of effective and inexpensive apparatus for collection. It also restricts application of cold spray system in open environment. Typically hermetical box is used with sucking system designed for gas flow rate been higher than gas flow rate of working gas (i.e. about or more than 1-2 m^3 per minute). Effective collection allows cost-effective production of arts by re-using the powder and prevents environment pollution.

Finally, successful marketing of cold spray technique requires industrial application where its usage is cost, time, and operation effectiveness. In the paper patents published within last 3 years and claim solution of typical problems in cold spray engineering, increasing effectiveness, reduce cost of both device units and product arts, prolong service term, and searching new application areas. Improvements are reached by material replacing, geometry changing, embedding additional parts into typical design etc. Application areas cover corrosive and wear resistant, electric and magnetic, and other barrier coatings and arts in automotive, aerospace, energy etc. industries.

MODIFICATIONS OF SPRAY SYSTEM

It is possible to divide modifications of cold spay systems into two main parts: modifications of spray unit and modifications of gas heater. These units of spray system are most important for providing effective coating, so great focus of inventor's attention on improvements of these units is not surprising. Also, in several articles inventors present modifications of other units like spray box, powder separators, etc.

Spray Unit Modifications

The aims of the most spray unit modifications are: providing best gas flow parameters and heat-velocity particle parameters required for adhesion, improvements of powder injection into gas flow, increasing of nozzle wear-resistance.

In [2, 3] authors patented the improved nozzle. The nozzle includes a powder/gas conditioning chamber that increases the particle residence time within the nozzle thereby enabling one to achieve higher particle temperatures prior to their acceleration in supersonic portion of the kinetic spray nozzle. The conditioning chamber has a length along a longitudinal axis equal to or greater than 20 mm. The conditioning chamber positioned between the exchange chamber and supersonic nozzle with the conditioning chamber in connection with the exchange chamber and supersonic nozzle. Supersonic nozzle having converging section separated from diverging section by a throat. The diverging section comprises a first portion and a second portion. The first portion has a cross-area that increases the length of the first portion and the second portion has a substantially constant cross-sectional area along with the length of the second portion. The converging section is connected to a second end of the powder/gas conditioning chamber opposite the first end (Fig. **3**). This configuration of kinetic spray nozzle system is more effective for heating and accelerating of particles.

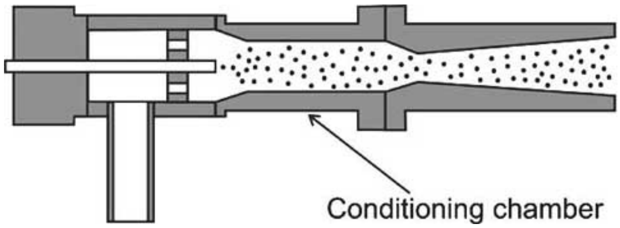

Fig. (3). Nozzle unit with conditioning chamber.

In patent [4] the modified kinetic spray nozzle with a rapid expansion rate in the diverging region relative to prior art nozzle is disclosed. This spray nozzle enables to achieve much higher particle velocities without an increase in the main gas temperature. Preferably, the expansion rate of the supersonic nozzle in a portion of diverging region is at least 1 mm^2 per millimeter, more preferably 5 mm^2 per mm, with a most preferable expansion rate being 10 mm^2 per millimeter.

One difficulty associated with most of spray systems is that the particle stream exiting the nozzle rapidly expands so small discrete spots or narrow lines of coatings. Instead, the smallest spots coatings are approximately 2 millimeters by 10 millimeters. To achieve finer coatings it is necessary to use masks. Using of masks is inconvenient and not always satisfactory. Thus, it is desirable to provide a method to permit kinetic spraying of discrete small volume areas. The nozzle with central body enables to create spot coating and very narrow width coating [5]. The nozzle includes a supersonic portion comprising a tubular section and a flow regulator. A portion of the flow regulator is received in the tubular portion. The flow regulator includes a biconical flow concentrator that allows one to create very small dimension coating on substrates (Fig. **4**).

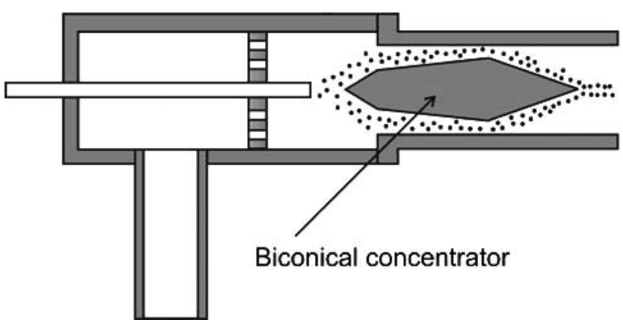

Fig. (4). Nozzle unit with flow concentrator.

Use of a collimator for turbulence reducing of the main gas is desirable [6]. Collimator have a central hole surrounded by a plurality of gas hole and a length of 10 to 30 millimeters with the gas flow holes having a hydraulic diameter of 0.5 to 5.0 millimeters. Collimator is located between a premix chamber and a mixing chamber.

Particle injecting into the flow also has several variants. Particles could be injecting not only into converging region of the nozzle, but also directly into the diverging region of the nozzle (Fig. **5**) at a point after throat [7].

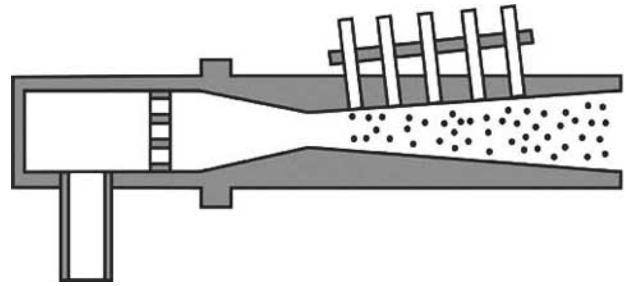

Fig. (5). Nozzle unit with particle injecting at a point after throat.

Some nozzle systems are involved in providing two populations of particles [8]. First population of particles is injecting into the diverging region of the nozzle, the second population is injecting into the converging region. The temperature of gas suggested be insufficient to heat the first population of particles to a temperature at or above their melting temperature in the nozzle and accelerating the particles to a velocity sufficient to result in adherence of the particles on a substrate positioned opposite the nozzle, and the temperature of the gas selected to be sufficient to heat the second population of particles to a temperature at or above their melting temperature in the nozzle thereby melting the second population of particles and accelerating the molten particles to a velocity sufficient to result in adherence of the particles on the substrate. Thereby a coating is formed on the substrate that is a combination of the first and second population of particles.

One problem with all prior art kinetic spray systems has been wear of the throat portion of the converging-diverging de Laval type nozzle. Because of restriction to flow caused by the throat it enlarges with use as the sprayed particles abrade the throat. In fact, the wear rate is approximately 10 fold faster in the throat than in the rest of the nozzle. It is possible to compensate for the wear up to a point by varying parameters, but there is a limit to the amount parameters can be varied. When the limit is reached the entire nozzle must be scrapped. The nozzles are expensive to produce because of the extensive machining that is required. Thus, it would be advantageous to develop a nozzle having a replaceable throat region to permit the nozzle to be used for much longer periods of time and at a lower cost. The replaceable throat insert for cold spray nozzle is used [9]. The supersonic nozzle has a first end opposite to the exit and a diverging region adjacent the exit end. A removable throat insert has an entrance cone and a throat is received in the first end with the throat positioned adjacent the diverging region. The removable throat insert has an entrance cone, a diverging region and a throat positioned between the entrance cone and diverging region (Fig. **6**). With the disclosed inserts a worn throat can rapidly and economically be replaced while saving the rest of the supersonic nozzle.

Typical nozzle materials which have been used in cold spay systems include brass, stainless steel and tool steel. During deposition of certain materials, namely aluminum and some nickel alloys, the nozzle will foul or clog with the metallic powder causing system failure and rework to remove the damaged nozzle. Fouling aluminum occurs

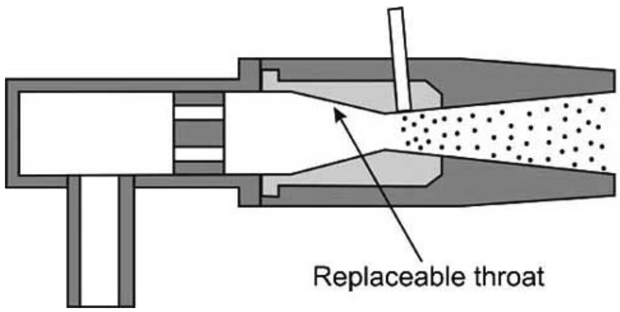

Fig. (6). Nozzle unit with replaceable throat.

within a matter of 3 - 4 minutes, whereas a minimum of 8 hours continuous operation is desired to commercialize this technology. The nozzle whose converging and diverging sections being formed from polybenzimidazole is an interesting way for solving this problem [10].

Improvements of Heater

In WO0506111691 [11] is provided a cold spray apparatus having a powder preheating device, capable of obtaining high deposi-tion rate and excellent coating layer under the same spray processing conditions by preheating coating powder before a coating process. A powder preheating device preheats the powder supplied from the powder feeder, and a mixing chamber mixes the heated main gas with the preheated coating powder (Fig. **7**). Using of preheating device especially necessary for the nozzles, having injection of particles into the diverging region. In diverging is exchange between particle and main gas is much lower than in converging region, so in some cases it is efficient to preheat powder before injecting into the flow.

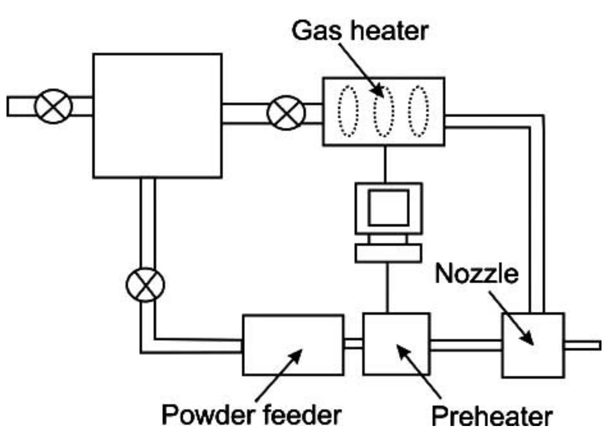

Fig. (7). Spray system with preheating device.

An alternative method for powder heating is also used. According to invention, energy is supplied to the particles with microwave technology [12]. For this purpose, the nozzle in which the gas jet and particles are accelerated is surrounded by a microwave waveguide and it encloses at least in part, the spray-free jet between the nozzle outlet and the substrate. Advantageously, one section of the nozzle outlet is made of a ceramic. The energy is supplied at a frequency of 915 MHz, 2.45 GHz and 5.8 GHz, respectively. Microwave radiation of these ISM frequencies can be handled well and therefore are suitable for heating the particles.

Other Improvements

During cold spray process a portion of material does not adhere to the substrate. In the case of using the system to abrade the substrate, none of the material adheres to the substrate. In both cases, it is desirable to collect loose material [13]. A cold spray system includes a spray nozzle for depositing material onto a substrate. A collection assembly at least partially surrounds the spray nozzle for vacuuming undeposited material and gases in the work area. The collection assembly includes a transparent collection tube at an end portion of the collection assembly to provide visibility to the work area. The collection assembly includes a shield having a flange that extends radially outwardly from the collection assembly and is generally parallel to a substrate. At angled portion of the shield extends from the collection assembly. A radius portion adjoins the flange and the angled portion. A ring is spaced between the spray nozzle and the shield. An inner surface of the ring deflects material that typically would otherwise not become adhered to the substrate back into collection assembly to minimize the material that must be vacuumed at the substrate. A curved surface of the ring extends from a surface spaced from the substrate toward the shield to provide a smooth transition for materials flowing along the substrate back into collection assembly.

A system with vacuum tank having both a substrate and cold spray gun located therein is provided [14]. The low ambient pressure (less than 1 atmosphere to 0.00001 atmospheres) in tank provides a more effective acceleration of spraying powder. Also this system can collect working inert gas and loose materials. Vacuum chamber is also used by inventors in paper [15].

FIELDS OF APPLICATION

A big number of application fields is the illustration of great potential of cold spray method. This type of spraying is very useful in application, which requires fast forming of coating without high temperature and material melting, low cost of process and reliability of devices.

Electroconductive Parts and Magnetic Conductors

The process for applying a kinetic spray coating of powder particles onto a substrate that covers a plastic-type material without first removing of plastic-type material is useful [16]. The process finds special use in forming electrical connectors or solderable pads anywhere along the length of flexible circuit. In this system electrical conductors, typically ribbon wire, are covered in plastic-type coating to protect them and to electrically isolate them from each other. Plastic-type material is meant to designate not only true plastics but also polyurethanes, polymers, nylons, rubbers and elastomers. Currently, when one desires to manufacture an electrical connection point or solderable pad somewhere along the flexible circuit it is necessary to remove the outer plastic covering in some manner prior to making the connection. Typically, this is done by laser ablation, using a punch wheel or milling. The exposed wiring is then cleaned and finally, electroplated. These steps are very time consuming, require a large manufacturing footprint, and generate waste problems. It is advantageous to develop a method for applying a cold spray coating onto a surface that is covered in a plastic-type material without requiring prior removal of plastic-type material. In one use of the process a mask is used to enable a single kinetic spray pass to both remove the plastic covering and bind particles having average nominal diameters from 60 to 250 microns to the underlying substrate. In another use of the process the particles have an average nominal diameter from 250 to 1400 microns and use of mask is optional because the particles can penetrate the plastic material and bind directly to the substrate. The particle used in invention are preferably either electrically conductive materials or solderable materials including: tin, tin alloys, especially tin silver alloys, aluminum, aluminum alloys, silver, silver alloys, gold, gold alloys, lead, lead alloys, zinc, zinc alloys and mixtures of these materials.

A method for deposition of a metal layer onto plastic materials is disclosed [17]. The method allows formation of long length strain gauges and deposition of high melting temperature metals onto plastic materials. The method comprises initially depositing a pattern of powder particles onto the plastic material using a kinetic spray process. Then the high melting temperature metal layer is deposited using a thermal spray process. The metal layer only adheres to the pattern of the powder particles and not to the plastic substrate. To form a stain gauge the powder particles are deposited in a discontinuous non-electrically conductive density on the plastic material. Then a metal layer is deposited using a thermal spray process and a metal having a variable resistance. The metal forms a continuous and electrically conductive pathway having a resistance that changes as stress is applied to the substrate.

Making electrical contacts on electroconductive substrate by kinetic spraying is an advantage [18]. Typically, for making contacts prior cleaning of substrate is necessary, but kinetic spray method can create contacts without first cleaning of surface. Firstly particles are cleaning substrate from oxides and after that, particles adhere onto substrate with making close electric contact. The materials of particles used in invention are: tin, silver, gold, platinum, brass and mixtures of these materials. Particles have a diameter from 25 to 106 microns. Powder feed rate and speed of substrate motion choose for creating spaced coating. Discontinuous layer formed by spraying process has a better resistance characteristic than electroplating formed by a continuous layer.

With the increased incorporation of electronic components and electrical systems in modern motor vehicles, there is a greater need for components and systems having circuits with high-current and better thermal management capabilities. Circuits with such capabilities are necessary to satisfy the high-power applications and requirements which are common in such modern motor vehicles. In general, for a circuit to meet such criteria, the metal conducting path must be sufficiently thick to minimize heat generation and to conduct or spread the heat or thermal energy to assist in circuit cooling. The invention [19] provides a copper-based circuit for use in high-current applications. According to the one embodiment, the copper-based circuit has an electrically insulative substrate, a bond layer including silver which is formed over select portions of substrate according to a desired shape of the circuit, and an electrically conductive layer including plastically deformed particles of copper deposited on the bond layer. In another embodiment, the copper particles are directly deposited onto a substrate without utilizing a bond layer. The substrate may include aluminum oxide, aluminum nitride or boron nitride. The bond layer may include, for example, a silver-palladium alloy, and that bond layer has a preferred thickness of approximately 10 to 12 microns. Desirably, each copper particle has a diameter of about 25 micrometers to about 150 micrometers. Preferably, each copper particle has a diameter of about 45 micrometers to about 65 micrometers when deposited on bond layer. Preferably, the particles have a size of 45 micrometers or less when deposited without bond layer.

Secure physical connection is necessary in many Industrial applications, particularly secure connections between metallic parts. The metallic parts can be formed from metal, alloy, or a combination thereof. Typically, these types of parts are secured to each other by welding, spot welding, fasteners, rivets, solders, brazing or adhesives. Often these procedures result in heating of the parts, which can be a disadvantage in many applications. In addition, many of these connection methods are time consuming. Making secure physical electrical connections in structures as multi-cell batteries is also important. These connections are used to connect the cells of multi-cell batteries in series or parallel depending on the needs of the electrical environment in which they are to be used. One type of battery, where such connections are of a particular importance, is lithium ion multi-cell battery. In the past the terminals of the individual cells of the battery that have been secured to one or two bus bars including ultrasonic welding, laser welding, capacitive discharge spot welding, soldering or mechanical means such as crimping. Method needs to meet several criteria including: the ability to bond dissimilar metals, electrical resistance of the connection that is below 0.2mOhm; low cost per connection; the ability to withstand mechanical, thermal and impact cycling; resistance to corrosion; ability to keep the temperature of the cell near connection below about 100 °C during formation of the connection to prevent thermal damage to the cell. A process for physical bonding of two parts to each other and for forming electrical connection have a low resistance is disclosed [20]. The process involves placing two parts or electrical conductors in contact with each other and then bonding them to each other using a kinetic spray process and powder particles. In formation of a multi-celled battery the particles are preferably electrically conductive. The connection can have an electrical resistance of less than 0.5 milliohms and strength equal or greater than ultrasonic welding.

Most “permanent” magnets and some “soft” magnets are produced through a molding and sintering operation from an admixture of magnetic materials and appropriate binders in an initially powdered form, wherein the final shape of the particular magnet is dictated by the mold tooling used. Additionally, "permanent" magnets must be magnetized by exposing the magnet to sufficiently high magnetic fields so as to introduce a strong, semi-permanent magnetic alignment of individual magnetic dipoles and lager physical domains. "Soft" magnetic materials, usually predicated on iron and several of its alloys, are often fabricated from sintered powders or laminated sheets, produced such that the intrinsic magnetic moment for the material is not permanent, but rather is determined by the magnitude of the applied field. Coils made predominantly from copper wire are used both to generate magnetic fields and electromagnetic torque in the airgap, with the ultimate goal to generate motion, as in an electric motor, or to generate electric power as in a generator or alternator. Electric machines, which may be either generators or motors, are thus assembled from specific geometric arrays of coils, magnetic material and supporting structures or carriers. Assembling processes for electric machines involve attachment of magnets, laminations and coils to housings designed to receive the magnet. When multiple magnets are assembled, it becomes difficult to precisely align and attach each magnet to the article or housing. A process that eliminates the molding, hardening and assembling steps can greatly simplify the construction process and reduce the cost. It is possible to thermal spray magnetic materials onto a carrier. But the intense heat from the thermal spray process causes the base metals to oxidize and produce oxides. The oxides produce much weaker magnetic fields than the base metals from which they originate. They lack the capacity to produce sufficiently strong fields required for motors and generators. The kinetic spray process is used for manufacturing magnets, so the magnetic material is not exposed to high temperatures [21]. It reduces the formation of unwanted oxides and enables the precise build-up of material atop carrier into the final desired shape of the magnet.

In article [22], authors are also patented a cold spray method and apparatus for the manufacture of electric circuits. Spray devices can produce a defined spray pattern with limited overspray. This results in possibility of manufacturing a patterned electric circuit board using little or no masking. Furthermore, this invention can be applied to a three-dimensionally contoured substrate. This opens up many new possibilities as an electric circuit can be sprayed onto practically any surface.

Brazing

Brazing is a process that involves the joining of components with a brazing filler material whose melting point is lower than either of the components. The brazing process is typically used to join components that are either metals or alloys. Typically, the brazing filler material is placed adjacent to or in between the two components to be joined and the assembly is then heated to a temperature where the brazing filler material melts but not the components. On cooling, the brazing filler material forms a metallurgical bond between the two surfaces of the components. Oftenly, the surfaces to be joined include surface metal oxide layers that can prevent formation of a good brazing joint between surfaces. Therefore, it is typical to include a brazing flux material in addition to the brazing filler material. Typical brazing flux contains either chlorides and/or fluorides and the flux material typically melts at a lower temperature than the brazing filler material. Once molten, the brazing flux material works to dissolve the hard shell of metal oxides on two surfaces, which enhances the wetting and flow of the molten brazing filler material, thereby allowing it to be drawn freely by capillary force between the joints of the components to be brazed. The composition of the brazing filler material is determined by the composition of the surfaces to be joined. Application of the brazing flux to the brazing surface prior to brazing of the apparatus is a difficult process. Typically, the brazing filler material is applied to one of the surfaces to be joined and the apparatus is pre-assembled. After pre-assembling the entire apparatus is often dipped in a water-flux slurry or such a water-flux slurry is sprayed onto the entire assembly. Alternatively, the flux material is applied on the entire apparatus via a static dry powder process. As discussed above, the flux is actually only required at the localized areas where the two surfaces are joined. The entire fluxed apparatus is then passed into a brazing furnace where the brazing flux material becomes a liquid and tends to drip from the apparatus forming very hard residues inside the brazing furnace, which requires the furnace to be shut down and cleaned periodically. In addition, the heated brazing flux material generates fumes that must be treated prior to release into the atmosphere. It would be advantageous to provide a method for direct application of a brazing flux material onto brazing surface that was simple and allowed the brazing surface with applied flux material to be handled extensively prior to the brazing process. In [23] authors patented a method for application of a brazing flux material to a brazing surface comprising the steps of applying a brazing filler material directly onto a substrate by a kinetic spray application to form a brazing surface and subsequently depositing a brazing flux material directly onto the formed brazing surface.

A process for preparing aluminum and aluminum alloy surface in heat exchanges for brazing by depositing thereon a kinetic sprayed brazing composition is also an advantage [24]. The process simultaneously deposits monolith or composite coating that can include all braze material and corrosion protection materials used in the brazing of aluminum fins to plates and tubes in single stage.

Repairing and Protecting of Surface

High pressure turbine (HPT) components, including turbine blades, are critical components in any turbine engine. During operation of the turbine engine, the HPT components are subjected to high heat and stress loadings as they experience operational conditions and are impacted by hot gas. This high heat and stress can result in unacceptably high rates of degradation on the turbine components due to erosion, oxidation, corrosion, thermal fatigue cracks and foreign object damage. Such conditions result in many cases in the need for repair and/or replacement, something that can result in significant operating expense and time out of service. Traditional methods of repair have had limited success. One primary reason for the lack of success is that the materials used to make HPT components do not lend themselves to conventional repair techniques. For example, many materials currently used in turbine blades and vanes suffer from poor ability for welding. Repairing the turbine blade with conventional welding techniques subjects the turbine blade to high temperatures. However, at such high temperatures the welding areas are likely to suffer severe oxidation. Also, repairing the HPT components with conventional welding techniques at room temperature is prone to form hot cracking in the welding area. This can require extensive reworking thus adding significantly to the cost of the repair.

A new method of repairing turbine engine components is provided [25,26]. The method utilizes a cold gas-dynamic technique to repair degradation on turbine blades, vanes and other components. Post-spray processing is then performed to consolidate and homogenize the applied materials and restore integrity to the material properties in the repaired turbine component.

A method for repairing a titanium alloy surface of a turbine component is also used [27]. Method includes the step of cold gas-dynamic spraying a powder material comprising at least one titanium alloy directly on the titanium alloy surface. The method may further include the steps of hot isostatic pressing the cold gas-dynamic sprayed turbine component, and performing a separate heat treating step after the hot isostatic pressing.

Cold gas-dynamic spray is used for spraying a powder material on the turbine component surface, the powder material comprising a mixture of MCrAlY powder and an abrasive powder such as cubic boron nitride, carbides, and oxides, with M being selected from Ni, Co and mixture thereof [28].

A method of fabricating a corrosion-resistant and inexpensive bipolar plate for a fuel cell is provided [29]. The bipolar plate fabrication method of the invention includes providing a stainless steel bipolar plate substrate which is typically a low-grade stainless steel, such as 304L or 316L, and forming a corrosion-resistant coating, which is a higher-grade stainless steel or alloy, on the bipolar plate substrate using a kinetic spray technique. The corrosion-resistant coating may be a high-grade stainless steel such as C-276. Other alloys such as 904L, 254SMO and carp-20, for example, can also be used as coating materials. Accordingly, the corrosion-resistant coating renders the lower-grade stainless steel bipolar plate substrates substantially resistant to fluoride ions in the fuel cell environment. This substantially prolongs the lifetime of the bipolar plate. A cover layer, which may be gold or an organic coating, may be provided on the corrosion-resistant coating to reduce the contact resistance of the corrosion-resistant coating.

A method of coating a vehicle wheel is very useful [30]. A method to increase wear and corrosion resistance of the vehicle wheel includes the steps of providing a vehicle wheel and applying a wear and corrosion resistant coating onto a surface of the vehicle wheel. The coating is applied to at least a tire bead retaining flange of the vehicle wheel. The coating is of particular use with vehicle wheels made of forged aluminum. The coating is selected from tungsten carbide, optionally including cobalt or chrome, a nickel-based superalloy, aluminum and silicon carbide, or stainless steel. The coating is typically about 0.1-0.25 mm. The surface of the vehicle wheel may be prepared by mechanically abrading the surface or chemically etching the surface of the vehicle wheel.

Perspective Coating

The adaptation of cold spray process to provide a method of coating fine metal particles (size of about 0.01 to about 10 micron), including aluminum and copper is desirable and possible [31].

Invention [32] is the means of depositing or near-net-shape forming nanostructured materials using a cold spray. The method can be used to create nanocrystalline layers of a wide variety of materials, e.g., pure metals and/or alloys. Examples of pure materials that can be used with the methods include, e.g., Al, Ni, Cu, and Ti. Examples of alloys that can be used with the methods of the invention include, e.g., aluminum alloy systems, nickel alloy systems, superalloy Ni-Ti-C systems, W-C-Co systems, and MCrAlY systems, wherein M is Ni, Co or Fe. Alternatively, the methods can be used to create nanocrystalline layers of composite materials e.g., a metallic matrix combined with one or more reinforcement phases. The reinforcement phases can be e.g., oxides, nitrides, and carbides, e.g., silicon carbides, aluminum oxide, boron carbide or aluminum nitride. The method of the invention uses material particles having nanocrystalline grain size in the range of 1 - 200 nm, 10 – 100 nm and 20 - 40 nm.

Cold spray is used for producing porous coating [33]. The method comprises providing the mother material, feeding powder having a metal composition, which includes at least two different metals selected from the group consisting of Al, Mg, Zn, and Sn and which is expressed by xA-(1-x)B (0, x, 1, where x is a weight ratio of A and B), onto the mother material, applying the metal powder on the mother material by spraying the metal powder by kinetic spray, and heat-treating the coated mother material to form the porous coating layer. In the method, it is possible to freely control the pore size and porosity of coated member.

CURRENT & FUTURE DEVELOPMENTS

The review of patents allows concluding the improvements concerning mainly of cold spray device units, exploitation conditions, cost reducing, and application areas.

Design of the nozzle unit suggested opens possibility of rapid change of wear parts and coating formation of wide range of materials and material mixtures (prepared before operation (e.g. by using different mills) or during operation directly inside nozzle-prechamber unit) including material mixtures of essentially different mechanical and thermal properties. The improvements are achieved due to particle inlet into supersonic part of nozzle that also allows significant decreasing pressure inside powder feeder. Particle heating is suggested due to direct heating of low-velocity gas-powder mixture prior to the inlet into prechamber or supersonic part of the nozzle. Particle heating with aid of microwave heating in supersonic part of the nozzle or in free jet is also suggested.

Improvements of spray unit open possibilities for providing a new ability of the cold spray (kinetic spray) technique in spraying of wide types of material and their mixtures.

The new fields of application of cold spray are also widely presented in inventor's patents. New technique finds an application in producing of electroconductive and magnetic devices, brazing process, repairing and protection of surface. Cold spray process is found to be able to produce coating with submicron structure and porous structure. These types of coating look perspective and can find application in new and original fields. Thus, abilities of cold spray technique are not exhausted and appearing of new fields of application is expected.

REFERENCES

[1] Klinkov SV, Kosarev VF, Rein M. Cold spray deposition: signification of particle impact phenomena. Aerosp Sci Technol 2005; 9: 582-591.
[2] Han, T., Zhao, Z., Gillespie, B.A., Smith, J.R., Rosen JR, J.S.: US20060040048A1 **(2006)**.
[3] Han, T., Zhao, Z., Gillespie, B.A.,Smith, J.R.: EP1579921A2 **(2005)**.
[4] Van Steenkiste, T. H., Han, T., Gillespie, B.A.: WO05072249A2 **(2005)**.
*[5] Van Steenkiste, T. H.: US20050211799A1 **(2005)**.
[6] Zhao, Z., Gillespie, B. A., Han, T., Smith, J. R., Fuller, B. K.: EP1508379A1 **(2005)**.
[7] Van Steenkiste, T. H., Gorkiewicz, D.W., Drew, G. A.: EP1445033A1 **(2004)**.
[8] Van Steenkiste, T. H., Fuller, B. K.: US20040058065A1 **(2004)**.
[9] Van Steenkiste, T. H., Gorkiewicz, D. W.: US20060038044A1 **(2006)**.
[10] Haynes, J. D., Sanders, S.A.: EP1462546A2 **(2004)**.
*[11] Kim, H.-J., Kweon, Y.-G.: WO05061116A1 **(2005)**.
*[12] Heinrich, P., Kreye, H., Stoltenhoff, T., Schmidt, T., Borchert, R., Ballhom, R.: US20060027687A1 **(2006)**.
[13] Baran, Z.: US20060081174A1 **(2006)**.
[14] Muehlberger, E.: WO03106051A1 **(2003)**.
[15] Haynes, J. D., Hobbs, D. A.: US20060121187A1 **(2006)**.
[16] Van Steenkiste, T. H., Gorkiewicz, D. W., Smith, J. R., Stier, M., Drew, G. A.: WO04091809A2 **(2004)**.
[17] Filler, B.K., Elmoursi, A.A., Van Steenkiste, T.H., Patel, N.B., Smith, J.R.: US20060013962A1 **(2006)**.
[18] Van Steenkiste, T.H., Drew, G.A., Gorkiewicz, D.W., Gillispie, B.A.: US20040072008A1 **(2004)**.
[19] Elmoursi, A.A., Lautzenhiser, F.P., Campbell, A. B., Smith, J. R.: EP1365637A2 **(2003)**.
[20] Teets, R. E., VanSteenkiste, T. H., Kruger, D. D., Beer, R. C.: US20060113359A1 **(2006)**.
[21] Ginder, J., McCune, R., Leonardi, F.: US20040202797A1 **(2004)**.
[22] Ogilvie, W.: WO05053367A2 **(2005)**.
[23] Zhao, Z., Gillispie, B. A., Smith, J. R., Van Steenkiste, T.H., Luo, Y.: EP1384545 A2 **(2004)**.
[24] Gillispie, B. A., Zhao, Z., Robert, S. J., Van Steenkiste, T. H., Elmoursi, A. A., Luo, Y., Hutchins, H. F.: US20030207148A1 **(2003)**.
[25] Hu, Y., Madhava, M., Renteria, F.: US20046905728B1 **(2004)**.
[26] Hu, Y., Renteria, F., Madhava, M.: US20050220995A1 **(2005)**.
[27] Hu, Y., Renteria, F., Cahoon, C. L., Floyd, M.: US20060045785A1 **(2006)**.
[28] Hehmann, W. F., Yiping, H., Renteria, F.: EP1634976A1 **(2006)**.
[29] Vyas, G., Abd Elhamid, M. H., Mikhail, Y. M., Blunk, R. H.: WO06049850A2 **(2006)**.
[30] Pajerski, A. V.: MXPA05003286A **(2005)**.
*[31] Liu, J.: US20060090593A1 **(2006)**.
*[32] Schoenung, J. M., Kim, G., Ajdelsztajn, L.: WO05079209A2 **(2005)**.
*[33] Ko, K. H., Lee, H. Y.: WO05078150A1 **(2005)**.