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(54) High velocity powder thermal spray method for spraying non-meltable materials.

(57) A method for producing a dense and tenacious coating with a thermal spray gun including a nozzle member and a gas cap. The gas cap extends from the nozzle and has an inwardly facing cylindrical wall defining a combustion chamber with an open end and an opposite end bounded by the nozzle. An annular flow of a combustible mixture is injected at a pressure of at least two bar above atmospheric pressure from the nozzle coaxially into the combustion chamber. An annular outer flow of pressurized air is injected from the nozzle adjacent to the cylindrical wall. Powder particles having a heat-stable, non-fusible component and a heat-softenable component, and entrained in a carrier gas, are fed axially from the nozzle into the combustion chamber. An annular inner flow of pressurized air is injected from the nozzle into the combustion chamber coaxially between the combustible mixture and the powder-carrier gas. Upon combusting the annular mixture a supersonic spray stream containing the powder is propelled through the open end to produce a coating.

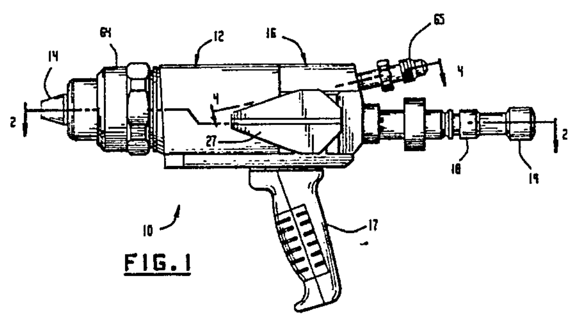

FIG. 1

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HIGH VELOCITY POWDER THERMAL SPRAY METHOD FOR SPRAYING NON-MELTABLE MATERIALS

This invention relates to thermal spraying and particularly to a method for combustion thermal spraying powder at very high velocity.

BACKGROUND OF THE INVENTION

Thermal spraying, also known as flame spraying, involves the melting or at least heat softening of a heat fusible material such as metal or ceramic, and propelling the softened material in particulate form against a surface which is to be coated. The heated particles strike the surface where they are quenched and bonded thereto. A thermal spray gun is used for the purpose of both heating and propelling the particles. In one type of thermal spray gun, the heat fusible material is supplied to the gun in powder form. Such powders are typically comprised of small particles, e.g., between 100 mesh U.S. Standard screen size (149 microns) and about 2 microns. Heat for powder spraying is generally from a combustion flame or an arc-generated plasma flame. The carrier gas, which entrains and transports the powder, may be one of the combustion gases or an inert gas such as nitrogen, or it may simply be compressed air.
Quality coatings of certain thermal spray materials have been produced by spraying at high velocity. Plasma spraying has proven successful with high velocity in many respects but it can suffer from non-uniform heating and/or poor particle entrainment which must be effected by feeding powder laterally into the high velocity plasma stream. U.S. Patent No.s 2,714,563 and 2,964,420 (both Poorman et al) disclose a detonation gun for blasting powdered material in a series of detonations to produce coatings such as metal bonded carbides. High density and tenacity of coatings are achieved by high impact of the powder particles, and the short dwell time in the heading zone minimizes oxidation at the high spray temperatures.

A rocket type of powder spray gun can produce excellent coatings of metals and metal bonded carbides, particularly tungsten carbide, and is typified in U.S. Patent Nos. 3,741,792 (Peck et al.) and 4,416,421 (Browning). This type of gun has an internal combustion chamber with a high pressure combustion effluent directed through a nozzle chamber. Powder is fed laterally into the flame or into the nozzle chamber to be heated and propelled by the combustion effluent.

Short-nozzle spray devices are disclosed for high velocity spraying in French Patent No. 1,041,056 and U.S. Patent No. 2,317,173 (Bleakley). Powder is fed axially into a melting chamber within an annular flow of combustion gas. An annular air flow is injected coaxially outside of the combustion gas flow, along the wall of the chamber. The spray stream with the heated powder issues from the open end of the combustion chamber.

Since thermal spraying involves melting or at least surface heat softening the spray material, non-meltable powders such as certain carbides and nitrides cannot be sprayed into successful coatings without incorporating a binder into the material. For example, powders may be formed by cladding a metal onto a core of non-meltable material as disclosed in U.S. Patent No. 3,254,970 (Dittrich et al.) or vice versa as disclosed in U.S. Patent No. 3,655,425 (Longo and Patel). However, such compositioning has not been fully sufficient for producing high quality coatings and optimum deposit efficiency with conventional thermal spray guns, vis. plasma or low velocity combustion.

Thermoplastic polymer powders such as polyethylene melt easily and many can readily be thermal sprayed. However, thermoset polymer powders generally do not melt, at least without first decomposing and/or oxidizing at the high thermal spraying temperature. Certain of these thermoset powders, as disclosed in U.S. Patent No. 3,723,165 (Longo and Durman) (assigned to the predecessor in interest of the present assignee) may undergo a superficial chemical or physical modification of the polymer surface of each particle so as to become surface heat softenable. An example is the poly (paraoxybenzoyl) ester powder described in U.S. Patent No. 3,784,405 (Economy et al). As further explained in Example 1 of the aforementioned U.S. Patent No. 3,723,165 such polyester may be utilized in a blend with aluminum alloy powder. Plasma spraying such a blend has been highly successful for producing abradable coatings for gas turbine engine seals and the like. However, the basic unmeltability of the polymer still results in poor deposit efficiency, so that even with the high heat available from a plasma gun, a significant portion of the polymer constituent is lost. Since this polymer is quite expensive, there is a need to improve the thermal spraying of the polymer-aluminum blend. There also has been an on-going need for improvements in abradability and erosion resistance of the coatings.

Therefore, objects of the present invention are to provide an improved method for thermal spraying non-meltable materials, to provide a method for high velocity thermal spraying particles having a non-meltable component and a heat softenable component, to provide an improved method of including non-meltable particles in thermal sprayed coatings at reasonable cost, to provide a method for thermal spraying improved coatings of certain non-meltable carbides and nitrides, and to provide a method for producing improved coatings of certain thermoset plastics.

SUMMARY OF THE INVENTION

The foregoing and other objects are achieved by a method for producing a coating with a thermal spray gun having a tubular member defining a combustion chamber therein with an open end for propelling combustion products into the ambient atmosphere at supersonic velocity. The method comprises injecting into the chamber a combustible mixture of combustion gas and oxygen at a pressure in the chamber of at least two atmospheres above ambient atmospheric pressure, feeding into the chamber a powder comprising particles having a heat-stable non-meltable component and a heat-softenable component, combusting the combustible mixture in the chamber whereby a supersonic spray stream containing the powder is propelled through the open end, and directing the spray stream toward a substrate such as to produce a coating thereon.

In a preferred embodiment the powder particles comprise composite grains of a metal and a non-meltable mineral, particularly in the form of metal clad mineral. More preferably, the mineral is selected from the group consisting of graphite diamonds, non-meltable carbides and non-meltable nitrides, such as silicon carbide, silicon nitride, chromium nitride, boron nitride, aluminum carbide and aluminum nitride.

Alternatively, the powder particles comprise thermoset polymer grains characterized by being surface heat softenable by flame modification. Preferably, the polymer grains comprise poly-(paraoxybenzoyl)ester, and the powder further comprises aluminum powder or aluminum base alloy powder.

In a preferred method, the thermal spray gun includes a nozzle member with a nozzle face and a tubular gas cap extending from the nozzle member and having an inwardly facing cylindrical wall defining a combustion chamber with an open end and an opposite end bounded by the nozzle face. This method comprises injecting an annular flow of combustible mixture of a combustion gas and oxygen from the nozzle coaxially into the combustion chamber at a pressure therein of at least two bar above atmospheric pressure, injecting an annular outer flow of pressurized non-combustible gas adjacent to the cylindrical wall radially outward of the annular flow of the combustible mixture, feeding a powder comprising particles having heat stable non-meltable cores and heat softenable surfaces in a carrier gas axially from the nozzle into the combustion chamber, injecting an annular inner flow of pressurized gas from the nozzle member into the combustion chamber coaxially between the combustible mixture.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation of a thermal spray gun used in the present invention.

FIG. 2 is a section taken at 2-2 of FIG. 1.

FIG. 3 is an enlargement of the forward end of the section of FIG. 2.

FIG. 4 is a section taken at 4-4 of FIG. 1, and a schematic of an associated powder feeding system.

FIG. 5 is a schematic view of the gun of FIG. 1 producing a supersonic spray stream according to the present invention.

FIG. 6 is the view of FIG. 5 with a substrate in place.

DETAILED DESCRIPTION OF THE INVENTION

An example of a preferred thermal spray apparatus for effecting the present invention is disclosed in copending U.S. Patent Application Serial No. 193,030 filed May 11, 1988, assigned to the assignee of the present invention and detailed herein. The apparatus is illustrated in FIG. 1, and FIG. 2 shows a horizontal section thereof. A thermal spray gun **10** has a gas head **12** with a tubular member in the form of a gas cap **14** mounted thereon, a valve portion **16** for supplying fuel, oxygen and air to the gas head, and a handle **17**. The valve portion **16** has a hose connection **18** for a fuel gas, a hose connection **19** for oxygen and a hose connection **20** for air. The three connections are connected respectively by hoses from a fuel source **21**, oxygen source **22** and air source **24**. Orifices **25** in a cylindrical valve **26** control the flow of the respective gases from their connections into the gun. The valve and associated components are, for example, of the type taught in U.S. Patent No. 3,530,892, and include a pair of valve levers **27**, and sealing means for each gas flow section that include plungers **28**, springs **29** and O-rings **30**.

A cylindrical siphon plug **31** is fitted in a corresponding bore in gas head **12**, and a plurality of O-rings **32** thereon maintain a gas-tight seal. The siphon plug is provided with a tube **33** having a central passage **34**. The siphon plug further has therein an annular groove **35** and a further annular groove **36** with a plurality of inter-connecting passages **38** (two shown). With cylinder valve **26** in the open position as shown in FIG. 2, oxygen is passed by means of a hose **40** through its connection **19** and valve **26** into a passage **42** from whence it flows into groove **35** and through passage **38**. A similar arrangement is provided to pass fuel gas from source **21** and a hose **46** through connection **18**, valve **26** and a passage **48** into groove **36**, mix with the oxygen, and pass as a combustible mixture through passages **50** aligned with passages **38** into an annular groove **52**. Annular groove **52** feeds the mixture into a plurality of passages **53** in the rear section of a nozzle member **54**.

Referring to FIG. 3 for details, nozzle member **54** is conveniently constructed of a tubular inner portion **55** and a tubular outer portion **56**. (As used herein and in the claims, "inner" denotes toward the axis and "outer" denotes away from the axis. Also "forward" or "forwardly" denotes toward the open end of the gun; "rear", "rearward" or "rearwardly" denotes the opposite.) Outer portion **56** defines an outer annular orifice means for injecting the annular flow of the combustible mixture into the combustion chamber. The orifice means preferably includes a forward annular opening **57** with a radially inward side bounded by an outer wall **58** of the inner portion. The orifice system leading to the annular opening from passages **53** may be a plurality of arcuately spaced orifices, but preferably is an annular orifice **59**.

The combustible mixture flowing from the aligned grooves **52** thus passes through the orifice (or orifices) **59** to produce an annular flow which is ignited in annular opening **57**. A nozzle nut **60** holds nozzle **54** and siphon plug **28** on gas head **12**. Two further O-rings **61** are seated conventionally between nozzle **54** and siphon plug **31** for gas tight seals. The burner nozzle **54** extends into gas cap **14** which is held in place by means of a retainer ring **64** and extends forwardly from the nozzle.

Nozzle member **54** is also provided with an axial bore **62**, for the powder in a carrier gas, extending forwardly from tube passage **33**. Alternatively the powder may be injected through a small-diameter ring of orifices (not shown) proximate the axis **63** of the gun. With reference to FIG. 4 a diagonal passage **64** extends rearwardly from tube **33** to a powder connection **65**. A carrier hose **66** and, therefore, central bore **62**, is receptive of powder from a powder feeder **67** entrained in a carrier gas from a pressurized gas source **68** such as compressed air by way of feed hose **66**. Powder feeder **67** is of the conventional or desired type but must be capable of delivering the carrier gas at high enough pressure to provide powder into the chamber **82** in gun **10**.

With reference back to FIGS. 2 and 3, air or other non-combustible gas is passed from source **24** and a hose **69** through its connection **20**, cylinder valve **26**, and a passage **70** to a space **71** in the interior of retainer ring **64**. Lateral openings **72** in nozzle nut **60** communicate space **71** with a cylindrical combustion chamber **82** in gas cap **14** so that the air may flow as an outer sheath from space **71** through these lateral openings **72**, thence through an annular slot **84** between the outer surface of nozzle **54**, and an inwardly facing cylindrical wall **86** defining combustion chamber **82** into which slot **84** exits. The flow continues through chamber **82** as an annular outer flow mixing with the inner flows, and out of the open end **88** in gas cap **14**. Chamber **82** is bounded at its opposite, rearward end by face **89** of nozzle 54.

Preferably combustion chamber **82** converges forwardly from the nozzle at an angle with the axis, most preferably between about 2° and 10°, e.g. 5°. Slot **84** also converges forwardly at an angle with the axis, most preferably between about 12° and 16°, e.g. 14.5°. Slot **84** further should have sufficient length for the annular air flow to develop, e.g. comparable to chamber length **102**, but at least greater than half of such length **102**. In addition, the chamber should converge at a lesser angle than the slot, most preferably between about 8° and 12°, e.g. 10° less. This configuration provides a converging air flow with respect to the chamber to minimize powder buildup on the chamber wall.

The air flow rate should be controlled upstream of slot **84** such as in a rearward narrow orifice **92** or with a separate flow regulator. For example slot length is 8 mm, slot width is 0.38 mm on a 15 mm circle, and air pressure to the gun (source **24**) is **4.9** kg/cm^2 (70 psi) to produce a total air flow of 425 std l/min (900 scfh) with a pressure of 4.2 kg/cm^2 (60 psi) in chamber **82**. Also, with valve **26** in a lighting position aligning bleeder holes as described in aforementioned U.S. Patent No. 3,530,892, an air hole **90** in valve **26** allows air flow for lighting, and the above-indicated angles and dimensions are important to allow such lighting without backfire. (Bleeder holes in valve **26** for oxygen and fuel for lighting, similar to air hole **90**, are not shown.)

The inner portion **55** of nozzle member **54** has therein a plurality of parallel inner orifices **91** (e.g. 8 orifices 0.89 mm diameter) on a bolt circle (e.g. 2.57 mm diameter) which provide for an annular inner sheath flow of gas, preferably air, about the central powder feed issuing from bore **62** of the nozzle. This inner sheath of air contributes significantly to reducing any tendency of buildup of powder material on wall **86**. The sheath air is conveniently tapped from passage **70**, via a duct **93** (FIG. 2) to an annular groove **94** around the rear portion of siphon plug **31** and at least one orifice **96** into an annular space **98** adjacent tube **33**. Preferably at least three such orifices **96** are equally spaced arcuately to provide sufficient air and to minimize vortex flow which could detrimentally swirl the powder outwardly to wall **86** of chamber **82**. The inner sheath air flow should be between 1% and 10%, preferably about 2% and 5% of the outer sheath flow rate, for example about 3%. The inner sheath may alternatively be regulated independently of the outer sheath air, for better control.

Chances of powder buildup are further minimized by having the inner portion **55** of the nozzle member protrude into chamber **82** forwardly of the outer portion **56** as depicted in FIGS. 2 and 3. A chamber length **102** may be defined as the shortest distance from nozzle face **89** to open end **88**, i.e. from the forwardmost point on the nozzle to the open end. The forwardmost point on the inner portion should protrude forwardly from the outer portion **56** by a distance between about 10% and 40% of chamber length **102**, e.g. 30%.

A preferred configuration for the inner portion is depicted in FIGS. 2 and 3. Referring to the outer wall **58** of inner portion **55** of the nozzle, which defines annular opening **57**, such wall **58** should extend forwardly from the annular opening with a curvature inward toward the axis. The curvature should be uniform. For example, as shown, the curvature is such as to define a generally hemispherical face **89** on inner portion **58**. It is believed that the combustion flame is thereby drawn inwardly to maintain the flows away from chamber wall **86**.

As an example of further details of a thermal spray gun incorporating the present invention, siphon plug **31** has 8 oxygen passages **38** of 1.51 mm each to allow sufficient oxygen flow, and 1.51 mm diameter passages **50** for the gas mixture. In this gas head central bore **62** is 3.6 mm diameter, and the open end **88** of the gas cap is 0.95 cm from the face of the nozzle (length **102**). Thus the combustion chamber **82** that also entrains the powder is relatively short, and generally should be between about one and two times the diameter of open end **88**.

A supply of each of the gases to the cylindrical combustion chamber is provided at a sufficiently high pressure, e.g. at least 30 psi above atmospheric, and is ignited conventionally such as with a spark device, such that the mixture of combusted gases and air will issue from the open end as a supersonic flow entraining the powder. The heat of the combustion will at least heat soften the powder material such as to deposit a coating onto a substrate. Shock diamonds should be observable. Because of the annular flow configuration, an expansion type of nozzle exit is not necessary to achieve the supersonic flow.

The combustion gas may be propane or hydrogen or the like, but it is preferable that the combustion gas be propylene gas, or methylacetylene-propadiene gas ("MPS"). These latter gases allow a relatively high velocity spray stream and excellent coatings to be achieved without backfire. For example with a propylene or MPS pressure of about 7 kg/cm^2 gauge (above atmospheric pressure) to the gun, oxygen at 10 kg/cm^2 and air at 5.6 kg/cm^2 at least 8 shock diamonds are readily visible in the spray stream without powder flow. The appearance of these shock diamonds **108** in spray stream **110** is illustrated in FIG. 5. The position of the substrate **112** on which a coating **114** is sprayed is preferably about where the fifth full diamond would be as shown in FIG.6, e.g. about 9 cm spray distance.

According to the method of the present invention certain powders are thermal sprayed with supersonic combustion spray guns. Although the preferred apparatus is as described above, the method may alternatively utilize other supersonic guns such as described in the aforementioned U.S. Patent No. 4,416,421. The certain powders are those that contain a heat-stable, non-meltable component in each powder grain. As used herein and in the claims the term "heat-stable" means that the referenced component will not substantially decompose or oxidize under the temperature and time conditions of the flame of the thermal spray gun; similarly the term "non-meltable" means that the referenced component will not substantially melt in the flame. As a test, the non-meltable component may be fed through a thermal spray gun to be used for the spraying thereof, collected and inspected microscopically and/or metallographically for decomposing, oxidizing or melting. For example, normal flattening of the particles on a substrate will indicate melting. Thus material that merely softens viscously, without a specific melting point to allow flattening on a substrate, is non-meltable for the purpose of this invention. Published handbooks on melting points are alternate sources of meltability information.

One group of heat-stable non-meltable materials contemplated, for use in the present invention are non-meltable minerals. Examples of such materials are graphite; diamond powder; non-meltable carbides such as silicon carbide and aluminum carbide; and non- meltable nitrides such as silicon nitride, chromium nitride, boron nitride and aluminum nitride. The mineral need not be naturally occurring. Silicon carbide and boron nitride are particularly preferable as described minerals to incorporate into coatings. The non-meltable material may be a heat stable thermoset polymer such as polyimide that is virtually unaffected by the thermal spray flame except for surface effects.

The non-meltable minerals, according to the invention, are composited with a meltable or at least a heat softenable component. Generally this component is a conventional thermal spray metal such as an iron-group element, molybdenum, aluminum, copper, or an alloy of any of these, or may be an oxide such as alumina, titania, zirconia, or chromia, or a complex oxide.

The composite powder is produced by the known or desired method. For example, metal clad mineral may be made by cladding the metal onto a mineral core as disclosed in the aforementioned U.S. Patent No. 3,254,970 (e.g. nickel clad diamond), by cladding fine mineral powder onto a metal core as disclosed in the aforementioned U.S. Patent No. 3,655,425 (e.g. boron nitride clad nickel alloy), or by agglomerating or spray drying fine powders of both components as disclosed in U.S. Patent No. 3.617,358 (Dittrich).

A second group of heat-stable non-metallic materials contemplated for the method herein consists of thermoset polymers. Thermoset is used broadly herein and in the claims to conventionally cover hydrocarbons (plastics) polymerized by heat, catalyst or reaction whereby the polymer is not ordinarily softenable by heating, for example without some chemical modification by the flame. The poly (paraoxybenzoyl) ester and copolyesters thereof of the aforementioned U.S. Patent Nos. 3,723,165 and 3,784,405 fall in this group, as may others such as certain epoxies and polyimides including those that may be in the form of an incompletely polymerized powder. A feature of these selected polymers is that only a surface portion is heat softened in the flame. This surface softening maybe is effected by chemical modification during the short exposure to the hot flame, changing a surface layer from thermoset to at least partially thermoplastic. Thus, for the purpose of the presently claimed invention, the surface layer is effectively a heat-softenable component and the core remains a heat-stable non-meltable component, even though the initial particle may be homogeneous. Alternatively a non-meltable thermoset polymer may be clad or otherwise composited with a meltable polymer such as polyamide, polyethylene or incompletely polymerized polyester or epoxy, or a copolyester of the type disclosed in aforementioned U.S. Patent No. 3,784,405. Characteristic powder according to the invention may be sprayed neat or blended with a more conventional thermal spray material such as a metal. Quite surprisingly, the method of supersonic combustion thermal spraying of the above-described powders is effected with relatively high deposit efficiency, and produces dense, high quality coatings. The high deposit efficiency is especially surprising because the short dwell time of particles in the supersonic flame would be expected to cause lesser deposit efficiency, especially with non-meltable components. The improved deposit efficiency provides not only a cost benefit per se but allows cost-favorable modification of blends to achieve a specified coating composition.

A preferred example is a blend of heat-stable polyester and aluminum alloy, as detailed in Example 1 below. Conventional plasma spraying, despite high heat, loses a considerable portion of the polyester relative to the alloy. Conventional, low-velocity combustion spraying chars the polyester or, with lesser heat, results in poorly cohesive deposits. Spraying with a supersonic combustion flame provides high deposit efficiency which allows a lesser proportion of polyester to be in the initial blend to obtain the originally specified proportions in the coating, and provides excellent coatings.

EXAMPLE 1

A blend of polyester plastic and aluminum alloy similar to the blend is prepared as described under Example 1-A of aforementioned U.S. Patent No. 3,723,165, except the plastic powder is 30% and the alloy is 70% by weight of the blend. The plastic is a high temperature aromatic poly (paraoxybenzoyl) ester sold under the trade name of EKONOL (TM) by the Metaullics Division of the Carboundary Company, Sanborn, N.Y. and has a size of -88 +44 microns, and the alloy is aluminum 12% silicon with a size of -44 +10 microns.

The blend is sprayed with the preferred apparatus described above with respect to FIGS. 1-3, specifically a Metco Type DJ (TM) Metaullics Division of the Carboundary Compass, Sanford, N.Y. Gun sold by The Perkin-Elmer Corporation, Westbury, New York, using a #3 insert, #3 injector, "A" shell, #2 siphon plug and #2 air cap. Oxygen was 10.5 kg/cm^2 (150 psig) and 212 l/min (450 scfh), propylene gas at 7.0 kg/cm^2 (100 psig) and 47 l/min (100 scfh), and air at 5.3 kg/cm^2 (75 psig) and 290 l/min (615 scfh). A high pressure powder feeder of the type disclosed in the present assignee's copending U.S. Patent Application Serial No. filed [attorney docket ME-3881] and sold as a Metco Type DJP powder feeder by Perkin-Elmer is used to feed the powder blend at 23 gm/min (3 lb/hr) in a nitrogen carrier at 8.8 kg/cm^2 (125 psig) and 7 l/min (15 scfh). Spray distance is 20 cm and the substrate is grit blasted nickel alloy.

Comparisons were made with the 40% powder and spraying thereof of Example 1-A of the '165 patent, the 40% powder being sold as Metco 601NS by Perkin-Elmer and containing 40% plastic powder, i.e. 1/3 more than the present 30% powder. The Example 1-A 40% powder was plasma sprayed conventionally with argon-hydrogen plasma gas. The 30% powder blend sprayed with the supersonic combustion gun yielded a deposit efficiency of 85%, vs typical 65% deposit efficiency for the 40% powder plasma sprayed. Of more importance is the fact that the coatings were of essentially the same composition as each other, reflecting the better deposit efficiency of the plastic constituent of the 30% powder with the supersonic combustion gun. Abradability and erosion resistance of the coatings were also essentially the same. Porosity for the high velocity coating was about 1% and uniformly dispersed, vs 5% non-uniform porosity for plasma sprayed 40% powder. Hardness for the high velocity coating was R15y 78 to 83, vs 65 to 75, i.e., again more uniform.

EXAMPLE 2

Nickel clad silicon carbide powder is prepared from -44 +5 micron silicon carbide powder. This is clad with nickel in the known manner by the hydrogen reduction of an ammoniacal solution of nickel and ammonium sulphate, using anthraquinone as the coating catalyst. Details of the coating process are taught in aforementioned U.S. Patent No. 3,254,970. The resulting powder containing 29% by weight silicon carbide, balanced nickel is screened to -53 microns.

The screened powder is sprayed with the apparatus of Example 1 with a #2 insert, #2 injector, "A" shell, #2 siphon plug and #3 air cap. Oxygen is at 10.5 kg/cm^2 (150 psig) and 286 l/min (606 scfh), propylene at 7.0 kg/cm^2 (100 psig) and 79 l/min (168 scfh), and air at 5.3 kg/cm^2 (75 psig) and 374 l/min (793 scfh). Powder feeder and carrier gas are the same as in Example 1 with a feed rate of 47 gm/min (6 lb/hr). Spray distance is 15 cm (6 inches) and the substrate is grit blasted mild steel.

Excellent, dense coatings were effected containing a high retained percentage and uniform distribution of silicon carbide. No discernable embrittlement was formed metallographically at nickel/silicon carbide particle interfaces, otherwise found in more conventional thermal sprayed coatings of such material, apparently due to short dwell time in the flame.

EXAMPLE 3

A powder of nickel-chromium-iron alloy core clad with fine particles of aluminum (3.5%) and boron nitride (5.5%), of the type described in aforementioned U.S. Patent No. 3,655,425 and sold as Metco 301NS by Perkin-Elmer is sprayed with the same gun and similar parameters as for Example 2. Dense, uniform coatings having an excellent combination of abradability and erosion resistance are effected.

EXAMPLE 4

Composite aluminum-graphite powder sold as Metco 310NS by Perkin-Elmer is produced by agglomerating fine aluminum -12% silicon -45 +10 microns) and 23% of graphite powder with 8% of an organic binder by the method used for making the powder of Example 3. This powder is sprayed with the same gun and similar parameters as for Example 2. Dense, uniform coatings having an excellent combination of abradability and erosion resistance are effected.

Example 5

Example 1 is repeated except that the polyester is replaced with a copolyester of recurring units of Formula I, III, and IV as disclosed in the aforementioned U.S. Patent No. 3,784,405 (incorporated herein by reference) and sold as Xydar(TM) by Dartco Manufacturing Inc., Augusta Georgia. Similar results are effected.

While the invention has been described above in detail with reference to specific embodiments, various changes and modifications which fall within the spirit of the invention and scope of the appended claims will become apparent to those skilled in this art. The invention is therefore only intended to be limited by the appended claims or their equivalents.

Claims

1. A method for producing a coating containing non-meltable material with a thermal spray gun having combustion chamber means therein with a combustion chamber and an open channel for propelling combustion products into the ambient atmosphere at supersonic velocity, the method comprising feeding through the open channel powder particles having a heat-stable non-meltable component and a heat-softenable component, injecting into the chamber and combusting therein a com-

bustible mixture of combustion gas and oxygen at a pressure in the chamber sufficient to produce a supersonic spray stream containing the powder issuing through the open channel, and directing the spray stream toward a substrate such as to produce a coating thereon.

2. A method for producing a coating with a thermal spray gun having a tubular member defining a combustion chamber therein with an open end for propelling combustion products into the ambient atmosphere at supersonic velocity, the method comprising injecting into the chamber a combustible mixture of combustion gas and oxygen at a pressure in the chamber of at least two atmospheres above ambient atmospheric pressure, feeding into the chamber a powder comprising particles having a heat-stable non-meltable component and a heat-softenable component, combusting the combustible mixture in the chamber whereby a supersonic spray stream containing the powder is propelled through the open end, and directing the spray stream toward a substrate such as to produce a coating thereon.

3. A method according to Claim 2 wherein the combustible mixture is injected at a sufficient pressure into the combustion chamber to produce at least 8 visible shock diamonds in the spray stream in the absence of powder-carrier gas feeding.

4. A method according to Claim 3 further comprising selecting the combustion gas from the group consisting of propylene gas and methylacetylene-propadiene gas.

5. A method according to Claim 2 wherein the powder particles are selected from the group consisting of the combusting mixture generates a flame and (a) composite grains comprising a metal and a non-meltable mineral and (b) thermoset polymer grains characterized by being surface heat softenable by the flame.

6. A method according to Claim 2 wherein the powder particles comprise composite grains of a metal and a non-meltable mineral.

7. A method according to Claim 6 wherein the mineral is selected from the group consisting of graphite, diamonds, non-meltable carbides and non-meltable nitrides.

8. A method according to Claim 6 wherein the mineral is selected from the group consisting of graphite, diamonds, silicon carbide, silicon nitride, chromium nitride, boron nitride, aluminum carbide and aluminum nitride.

9. A method according to Claim 6 wherein the mineral consists essentially of boron nitride, and the metal comprises nickel or cobalt or alloys thereof.

10. A method according to Claim 6 wherein the mineral consists essentially of silicon carbide and the metal comprises nickel or cobalt or alloys thereof.

11. A method according to Claim 2 wherein the combusting mixture generates a flame and the powder particles comprise thermoset polymer grains characterized by being surface heat softenable by the flame.

12. A method according to Claim 11 wherein the polymer grains comprise poly(paraoxybenzoyl)-ester.

13. A method according to Claim 12 wherein the polymer grains consist essentially of poly-(paraoxybenzoyl)ester.

14. A method according to Claim 12 wherein the polymer grains consist essentially of a copolyester of poly(paraoxbenzoyl)ester.

15. A method according to Claim 11 wherein the powder further comprises aluminum powder or aluminum base alloy powder.

16. A method for producing a dense and tenacious coating with a thermal spray gun including a nozzle member with a nozzle face, and a tubular gas cap extending from the nozzle member and having an inwardly facing cylindrical wall defining a combustion chamber with an open end and an opposite end bounded by the nozzle face, the method comprising injecting an annular flow of a combustible mixture of a combustion gas and oxygen from the nozzle coaxially into the combustion chamber at a pressure therein of at least two bar above atmospheric pressure, injecting an annular outer flow of pressurized non-combustible gas adjacent to the cylindrical wall radially outward of the annular flow of the combustible mixture, feeding a powder comprising particles having heat stable non-meltable cores and heat softenable surfaces in a carrier gas axially from the nozzle into the combustion chamber, injecting an annular inner flow of pressurized gas from the nozzle member into the combustion chamber coaxially between the combustible mixture and the powder-carrier gas, combusting the combustible mixture, whereby a supersonic spray stream containing the heat fusible material in finely divided form is propelled through the open end, and directing the spray stream toward a substrate such as to produce a coating thereon.

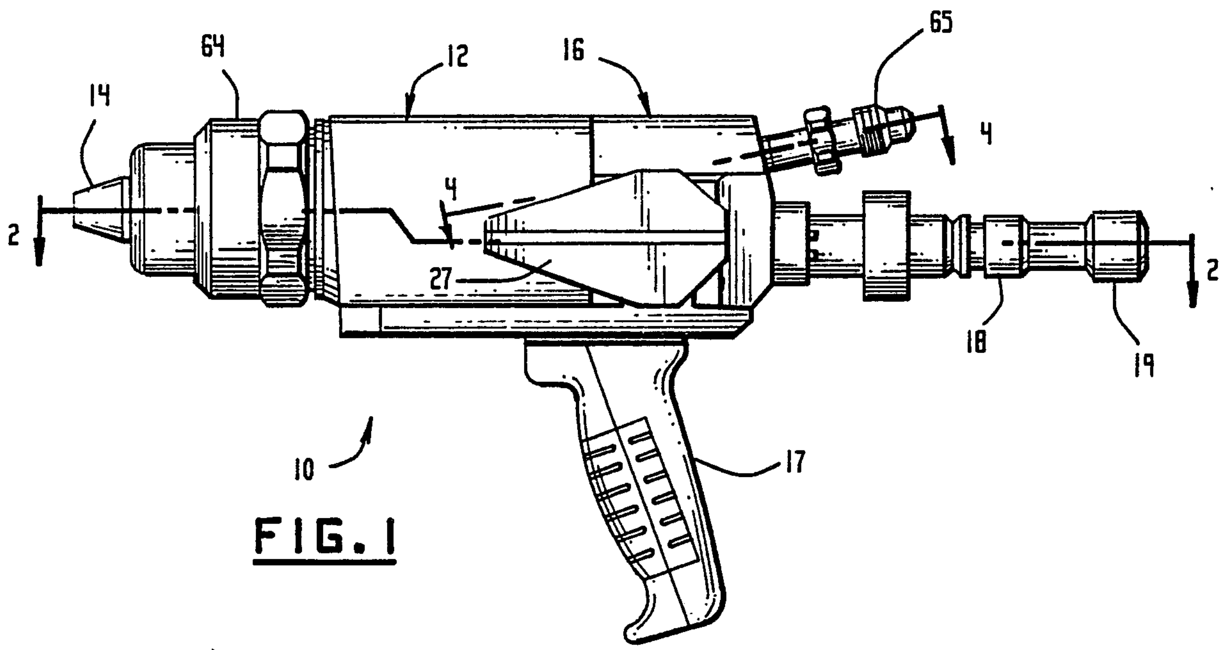
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FIG. 1

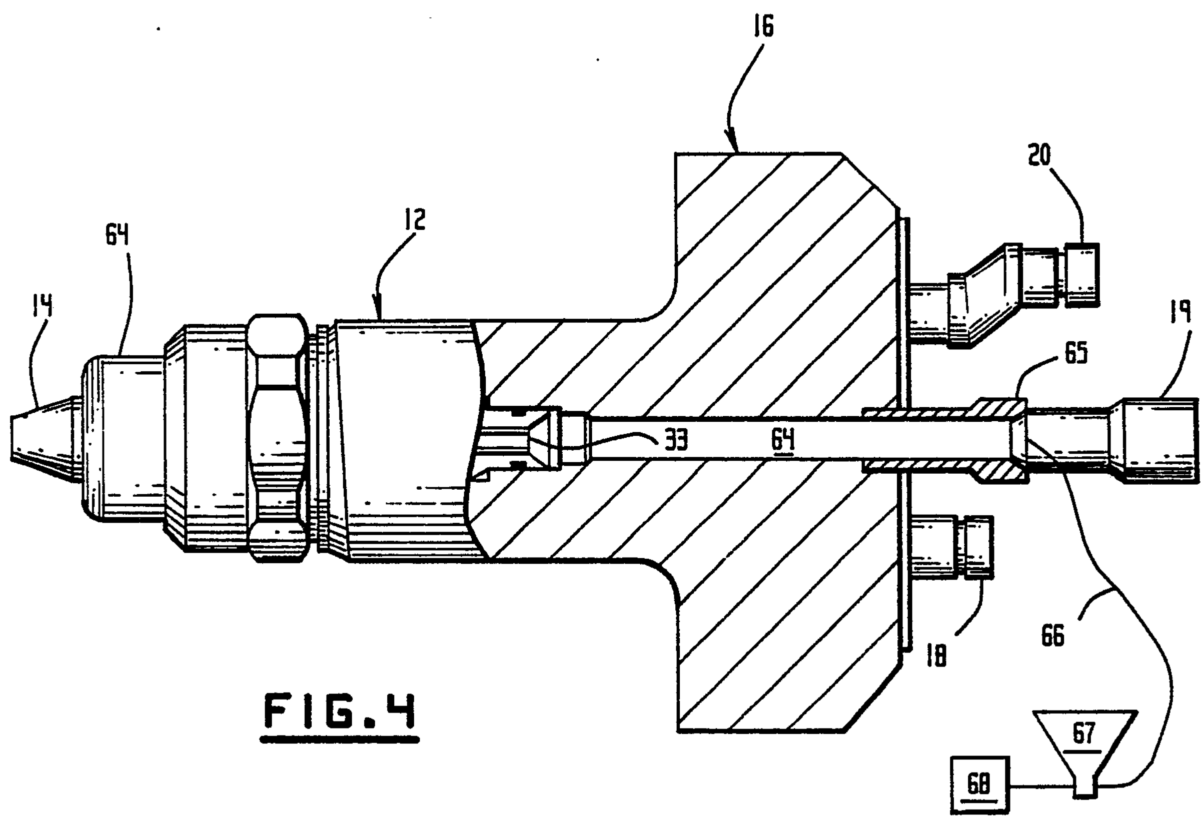
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FIG. 4

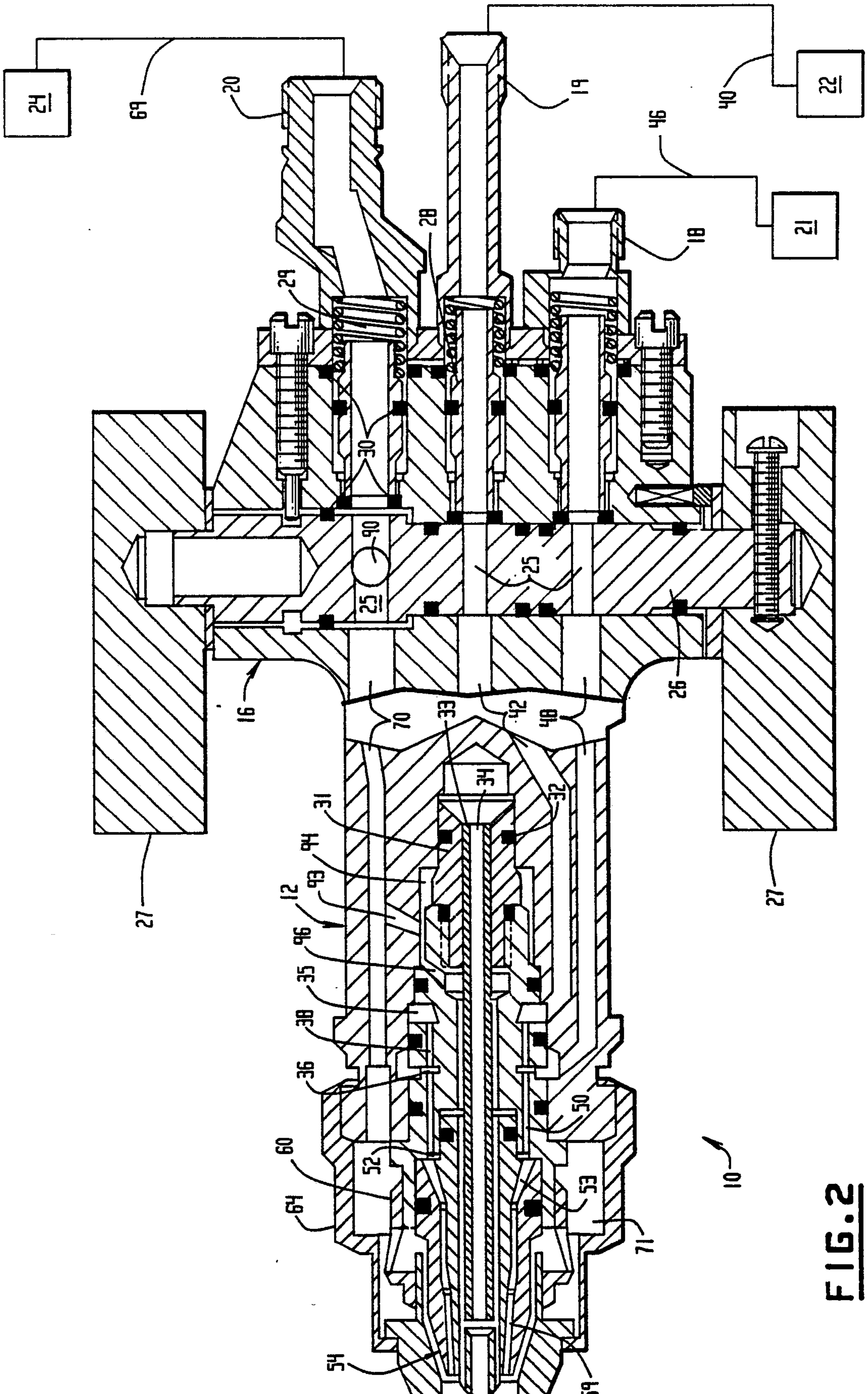
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FIG.2

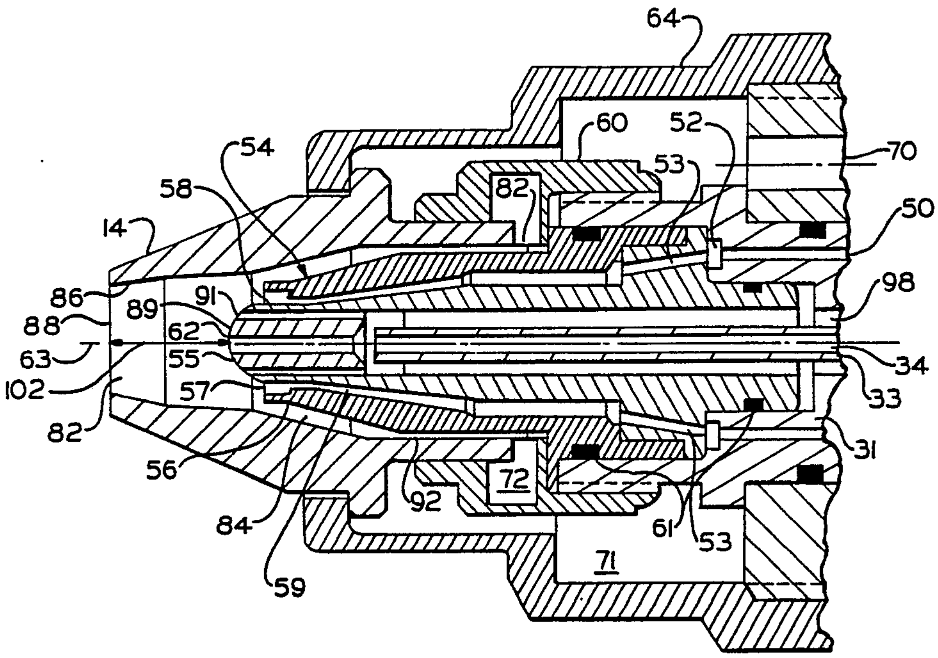

FIG.3

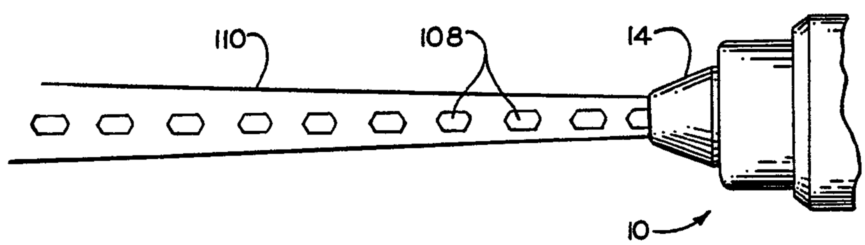

FIG.5

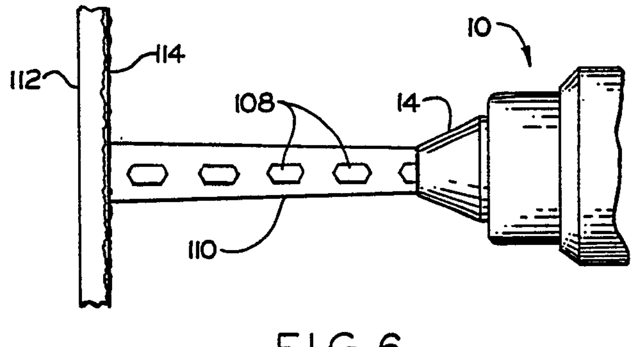

FIG.6