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(73) Proprietor: **PLASMA-TECHNIK AG**
Rigackerstrasse 21
CH-5610 Wohlen 1(CH)

(72) Inventor: **Marantz, Daniel R.**
25 Cedar Lane
Sans Point, NY 11050(US)
Inventor: **Rangaswamy, Subramaniam**
348 Oxhead Road
Stony Brook, NY 11790(US)
Inventor: **Miller, Robert Alvin**
14110 Balfour Avenue
Oak Park, MI 48237(US)

(74) Representative: **Rottmann, Maximilian R.**
c/o Rottmann, Zimmermann + Partner AG
Glattalstrasse 37
CH-8052 Zürich (CH)

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Description

The present invention relates to materials and coatings, especially those which abrade readily, such as for example coatings used to form abradable seals in turbine engines. More particularly, it relates to an improved abradable material and its method of manufacture.

Materials which abrade readily in a controlled fashion are used in a number of applications, including as abradable seals. As will be appreciated by those skilled in the art, contact between a rotating part and a fixed abradable seal causes the abradable material to wear away in a configuration which mates with the moving part at the region of contact. That is, the moving part scrapes away a portion of the abradable seal so that the seal takes on a geometry which precisely fits the moving part. This effectively forms a seal having an extremely close tolerance.

One particular application of abradable seals is their use in turbine engines. Typically, the inner surface of the turbine shroud is coated to a predetermined thickness with an abradable material using a spray gun. In operation, as the turbine blades rotate, they expand somewhat due to the heat which is generated. The tips of the rotating blades then contact the abradable material and carve precisely defined grooves in the coating without contacting the shroud itself. It will be understood that these grooves provide the exact clearance necessary to permit the blades to rotate and thus afford an essentially custom-fitted seal.

In order for the turbine blades to cut grooves in the abradable coating, the material from which the coating is formed must abrade easily without wearing down the blade tips. This requires that a careful balance of materials in the coatings be achieved. In this particular environment, an abradable coating must also exhibit good resistance against particle erosion and other degradation at elevated temperatures. However, as known by those skilled in the art, these desirable characteristics are difficult to obtain using conventional methods of forming abradable coatings.

More specifically, many conventional abradable coatings are formed by plasma spraying the filler and metallic components as a powder, which requires that a number of parameters be carefully monitored. These parameters include the compositional characteristics of the feed powder, powder size, and the various operating conditions of the spray gun. However, even when these factors are closely monitored, conventional equipment and techniques have not been consistently successful in producing high-quality abradable coatings.

In more detail, conventional composite abradable coatings are fabricated by thermal spraying a feedstock selected from two general types. The simplest of these comprises a mixture of a metallic powder and a filler which is usually a non-metallic powder. That is, a blend of the discrete particles of each constituent is prepared which is then sprayed using a plasma spray gun. However, these powder mixtures often segregate, not only in storage, but also in the particle spray stream itself, both of which adversely affect the microstructure of the resultant coating. It is known that particle segregation produces localized regions in the coating consisting predominantly of a single powder constituent. This in turn produces coatings of non-uniform composition and hardness which have inferior serviceability. This lack of uniformity may also be caused by preferential vapourization or other thermal transformation of one of the powder constituents, particularly where a plastics material is used as a component. In addition, the use of mixed or blended powders also makes it difficult to adjust the ratio of the constituents to produce graded coatings requiring different blends of feedstock for each layer of the coating.

In the other general class of spray powders, the two constituents are bonded together to form composite particles. A number of bonding techniques are known, such as for example, cladding a first material in powder form with a second material, or by simply bonding two powders together with a suitable binder. However, the binder may not be effective in preventing separation of the two dissimilar materials. Moreover, not only are cladding techniques expensive, but there may also be preferential vapourization of the cladding, which reduces the compositional balance of the coating, and a single powder composition cannot be used to form a coating having different characteristics through the depth of the coating.

For many materials, the production of satisfactory abradable coatings requires the use of extremely high velocities which cannot be achieved with conventional combustion flame spray guns. While plasma spray guns provide high velocities, they operate at such high temperatures that they can cause vapourization and thermal degradation, such as for example, vapourization of the plastics constituent and oxidation of the powder constituents, the latter being accelerated by the turbulence of the spray stream.

In Patent Abstracts of Japan, Vol.12, No.372 (C-533) reference is made to a purpose of forming a uniform and good thermally sprayed layer of a metal-based composite material by melting wire rods which serves as a matrix by an arc and blowing the molten metal thereof together with a fine reinforcing material by gas.

According to that Abstract a pair of wires consisting of the metal is supplied through nozzles and an arc is generated to melt the wires. Fine reinforcing material is transported by a gas through the metal wires to thermally spray a surface.

It would be desirable to provide a method for forming an abradable material by which the problem of particle segregation can be reduced or eliminated. It would also be desirable to provide such a method with the added feature of producing high-quality abradable coatings without producing any significant degradation of the feedstock. It would further be desirable to provide such a method by which a compositional gradient could be attained in a coating by allowing independent control of feedstock constituents without the use of a complex powder metering system and which avoids the steep temperature and velocity gradients of plasma spraying. The present invention provides a method of forming an abradable material which achieves these goals and also provides a novel abradable material formed by the method of the present invention.

According to the present invention there is provided a method for making an abradable material which comprises axially feeding a filler into a stream of high-temperature combustion gases to entrain the filler in the stream of high-temperature combustion gases; atomizing a molten metal with the stream of high-temperature combustion gases having the entrained filler such that the atomized molten metal is entrained in the stream of high-temperature combustion gases along with the filler; directing the stream of high-temperature combustion gases having the entrained filler and the entrained atomized molten metal towards a target; the filler and the atomized metal entrained in the stream of high-temperature combustion gases forming a deposit on the target, the deposit comprising an abradable material having a metal matrix in which the filler is embedded.

In one aspect, the present invention provides a method for making an abradable material by introducing a filler, preferably in particulate form, and more preferably a powdered non-metal, such as, for example, a plastics material into a stream of high-temperature combustion gases, thereby entraining the filler in the gas stream. The filler is preferably fed axially into the combustion gas stream, thereby avoiding uncontrolled lateral dispersement as the particles enter the high-velocity gas stream. The filler is heated and propelled at an extremely high velocity by the combustion gases along an axis which intersects a molten metal. The stream of the high-temperature combustion gases in which the filler is carried atomizes the molten metal such that the molten metal is entrained in the stream along with the filler. Thus, a composite

stream is formed containing both the filler and the atomized molten metal. The composite stream or spray is then directed toward a target, whereby the heated filler and molten metal impact the target surface at a high velocity to form a layer or coating of an abradable material. Upon impact, the molten metal forms a substantially continuous metal matrix in which the filler is embedded in the interstices. The resultant coating is readily abradable and is well adapted for use in forming abradable seals.

In one preferred aspect, the method of the present invention is carried out using the high-velocity flame spray apparatus disclosed in our copending European Patent Application 89309078.7 (EP-A-0 361 710). Therein, a flame spray apparatus is disclosed which includes a body portion having a feedstock bore with an inlet adapted to receive a feedstock and an outlet communicating with a converging throat. The converging throat is preferably coaxially aligned with the feedstock bore. The body includes a fuel passage with a fuel-receiving inlet and an outlet surrounding the feedstock bore and communicating with the converging throat. The body portion of the gun is further provided with an oxidant passage having an inlet adapted to receive an oxidant gas and an outlet communicating with the throat. Hence, the throat separately receives a fuel and an oxidant from the passage outlets prior to any mixing of the fuel and the feedstock filler. The throat includes a conical wall which is spaced sufficiently from the fuel and oxidant outlets to provide mixing and partial combustion of the fuel and oxidant within the throat. Upon ignition of the fuel and oxidant, a flame front is established within the throat that rapidly heats the incoming fuel liberating energy by the resultant chemical reactions to provide the driving force for sustaining a continuous high-velocity diffusion reaction. In this manner, the feedstock is accelerated through an outlet at the apex of the conical wall. The apex of the conical wall is in alignment with the feedstock bore, whereby the accelerated feedstock is directed through the gun barrel toward the tip opening in a straight bore nozzle. In one embodiment, the heated combustion gases carrying the feedstock are at a temperature sufficient to melt the tip of a metal wire which is then atomized by the high-velocity gas stream. In another embodiment, a two-wire electric arc assembly is included with the preferred spray apparatus such that electric arc heating of the wires melts the wire tips, whereby the molten metal is atomized and entrained in the stream issuing from the gun throat to form a composite spray.

In still another aspect, the present invention provides abradable materials which exhibit superior uniformity and which have lower metal oxide content than many conventionally sprayed materials.

The abradable materials comprise a matrix of metal in which a filler, preferably a soft, friable non-metal is uniformly dispersed in the matrix. In one embodiment, the abradable materials of the present invention comprise composite abradable seals for use in such applications as abradable turbine engine seals. The inventive abradable materials and seals are formed using the method of the present invention. In one preferred embodiment, the abradable materials of the present invention comprise a metal matrix in which a plastic is uniformly distributed in the matrix interstices.

According to an embodiment of the present invention there is provided a method for forming an abradable coating which comprises injecting a particulate filler feedstock substantially axially into a stream of high-temperature combustion gases flowing through a spray gun such that the particulate filler feedstock is entrained in the stream of high-temperature combustion gases; atomizing one end of at least one molten metal wire by placing the one end of the one molten metal wire in the path of the stream of high-temperature combustion gases such that the molten metal is entrained in the stream along with the particulate filler feedstock; directing the stream having the entrained particulate filler feedstock and the atomized molten metal to a surface to be coated; and coating the surface with the particulate filler feedstock and the molten metal from the stream to form an abradable coating on the surface, the abradable coating including a substantially continuous metal matrix, the interstices of the metal matrix being filled with the particulate filler feedstock.

According to another embodiment of the present invention there is provided a method for forming an abradable metal matrix composite coating for use as an abradable seal which comprises injecting a powdered filler feedstock by introducing the powdered filler feedstock substantially axially into a stream of rapidly expanding high-temperature, high-velocity combustion gases in a spray gun; atomizing a molten metal by directing the stream of high-temperature combustion gases carrying the powdered filler feedstock at the tip of at least one metal wire such that a composite stream of high-temperature, high-velocity combustion gases is formed in which the powdered filler feedstock and the molten metal are entrained; and depositing the filler and the molten metal on a surface by directing the composite stream at the surface such that the filler and the molten metal impact the surface at a high velocity to form an abradable composite coating on the surface to serve as an abradable seal.

The present invention thus provides a novel abradable material and a method of making the abradable material. In a preferred embodiment, the

material of the present invention is formed as an abradable coating on the surface of a part. In its most preferred embodiment, the abradable coating of the present invention comprises an abradable seal.

In accordance with the method of the present invention, a stream of high-temperature, high-velocity combustion gases is formed with a combustion flame spray apparatus, the most preferred configuration of which is set forth in our copending European Patent Application referred to above (claiming priority from United States patent application Serial No. 247,024). It will be understood by those skilled in the art, however, that other, preferably high-velocity, spray systems may be utilized to accelerate the filler particles.

The present invention will now be described with reference to the accompanying drawings, but in no manner limited thereto.

In the drawings:-

Figure 1 is a cross-sectional view of a preferred flame spray apparatus for use in practising the method of the present invention, the wire and wire feed mechanism not being illustrated in this view for simplicity;

Figure 2 is a plan view of the preferred flame spray apparatus for use in the present invention in which a two-wire arc assembly is shown;

Figure 3 is a diagrammatic representation which demonstrates the formation of a flame front in the converging throat of the spray gun and the creation of a composite collimated particle stream which forms the abradable material of the present invention; and

Figure 4 is a photomicrograph of an abradable material in cross-section made in accordance with the present invention.

Referring now to the drawings (and particularly Figure 1), flame spray apparatus 10 is illustrated generally having burner housing 12, which is shown integral with barrel 14. Conical wall 16 of burner housing 12 defines a converging throat 18 in which a continuous high velocity diffusion reaction is carried out. Feedstock supply bore 20 is defined by feedstock supply tube 22, which is closely received within feedstock housing 24. Feedstock housing 24 in the disclosed embodiment is provided with a threaded end 26 which is received in a tapped portion of burner housing 12. Collar 28 may be provided to aid in seating feedstock housing 24 in position. Feedstock housing 24 and feedstock supply tube 22 are disposed within fuel supply nozzle 30, such that an annular fuel passage 32 is defined. End 34 of fuel nozzle 30 is preferably tapered and press-fitted into burner housing 12.

Feedstock housing 24 includes a second collar or flange portion 36 which engages fuel nozzle 30.

Collar 36 is provided with longitudinal channels axially aligned with feedstock bore 20. Fuel flowing through annular passage 32 in the direction shown by the arrows is thus not significantly obstructed by collar 36 during operation. That is, collar 36 has a channelled outer surface such that it can function as a spacer with respect to fuel nozzle 30 and yet still allow substantially unobstructed flow of fuel through annular fuel passage 32. In a similar manner, end portion 38 of fuel nozzle 30 is provided with a series of substantially parallel longitudinal channels. Again, this channel construction allows end portion 38 of fuel nozzle 30 to engage conical wall 16, while permitting an oxidant to flow through annular oxidant passage 40 into converging throat 18. Annular oxidant passage 40 is an annulus defined by sections 42 and 44 of burner housing 12. It will be noted that section 44 also provides conical wall 16. In order to rigidly attach section 44 to section 42, section 42 is tapped to receive a threaded portion of section 44.

Leading into annular fuel passage 32, fuel supply passage 48 is provided which extends through end portion 50 of burner housing 12 and is in flow communication with annular fuel passage 32. This continuous passage serves as a channel through which a fuel is conveyed to a flame front in converging throat 18. Similarly, annular oxidant passage 40 is in flow communication with oxidant inlet passage 52. End portion 50 includes connector 54 which may be threaded for the connection of a feedstock supply hose as will be explained more fully in the method of the present invention. A filler feedstock is introduced into feedstock bore 20 via connector 54.

The cross-sectional area of feedstock bore 20 is preferably substantially less than the cross-sectional area of annular fuel passage 32 and annular oxidant passage 40, such that powdered feedstock is fed into converging throat 18 at a sufficient velocity to move through converging throat 18. Supply bore 20 is generally less than about 15% of the cross-sectional areas of either annular fuel passage 32 or annular oxidant passage 40. Also, the ratio of the diameter of supply bore 20 to the internal diameter of spray passage 56 is generally about 1 to 5. The ratio of cross-sectional areas is thus generally about 1 to 25.

Barrel 14, which is a tubular straight bore nozzle, includes hollow cylindrical section 46 which defines spray passage 56. As will be described more fully, high-velocity particles of a filler feedstock are propelled through passage 56 as a collimated stream. In order to prevent excessive heating of barrel wall 46 and to provide an effect referred to herein as "thermal pinch", a phenomenon which maintains and enhances collimation of the particle stream, heat exchange jacket 58 is

provided which defines an annular heat exchange chamber 60. Heat exchange chamber 60 is limited to barrel 14, so that heat is not directly removed from converging throat 18. In use, a heat exchange medium, such as, for example, water, is flowed through heat exchange chamber 60 via channel 62 and 64. Hoses (not shown) are each attached at one end to connectors 66 and 68 to circulate heat exchange medium through heat exchange chamber 60.

Referring now to Figure 2 of the drawings, flame spray apparatus 10 includes a molten metal supply means illustrated here as a two-wire electric arc assembly (not shown in Figure 1 for simplicity). Arc assembly 70 includes carriage 72 which houses wire guides 74 and 76. Wire guides 74 and 76 are provided to guide wires 78 and 80 at a predetermined rate toward arc zone 82. The included angle of wires 78 and 80 is preferably generally less than about 60 degrees in most applications. In a preferred method herein, an electric arc of predetermined intensity is struck and continuously sustained between the ends of the wire electrodes. In another embodiment, the heat of the collimated combustion gas stream melts the tips of wires 78 and 80. It may be suitable in some applications to use a single wire 78, wherein the heat of the combustion gases melts the wire. In the disclosed embodiment, wires 78 and 80 are continuously fed toward an intersecting point in arc zone 82 as they are melted and consumed as atomized molten metal. While the distance of arc zone 82 from the end of barrel 14 is not critical and can be adjusted to regulate various characteristics of the coating or article which is formed during the spraying operation, the ends of wires 78 and 80 are preferably located from about 4 to about 10 centimetres from the end of barrel 14 in most applications. The arc and molten metal wire ends should be positioned within the collimated particle stream issuing from barrel 14; that is, along the longitudinal axis of barrel 14.

A number of fuel and oxidant sources may be used in the present invention. Gas, liquid or particulate fuels or oxidants may be suitable as described in our copending European Patent Application referred to hereinabove. For the oxidant, most oxygen-containing gases are suitable. Substantially pure oxygen is particularly preferred for use herein. Suitable fuel gases for achieving high-velocity thrust of spray materials in the present invention are hydrocarbon gases, preferably high-purity propane or propylene, which produce high-inertia oxidation reactions. Hydrogen and other liquid and gaseous fuels may also be suitable in some applications. In the present invention, flame temperature and thus the temperature of the filler feedstock, can be controlled by proper fuel selection as

well as by controlling gas pressures and the dwell or residence time of the feedstock particles in converging throat 18 and bore 56.

Also, by controlling the composition of the fuel and the gas pressure, a wide range of particle velocities can be obtained. The preferred fuel gas pressure is from about 137.9 to about 689.5 kPa (about 20 to 100 psig) and more preferably from about 275.8 to about 482.7 kPa (about 40 to about 70 psig). The oxidant gas pressure will typically range from about 137.9 to about 689.5 kPa (about 20 to about 100 psig) and preferably from about 275.8 to 551.6 kPa (about 40 to about 80 psig) for most applications. When operating within these ranges, velocities of the combustion products emerging from barrel 14 will be supersonic and significantly greater than velocities of other conventional commercial flame spray guns under similar operating conditions. It will be appreciated that the nature of the fuel gas and its mass flow characteristics closely dictate velocity.

Referring now to Figure 3 of the drawings, flame spray apparatus 10 is shown diagrammatically in which a filler feedstock 110 is injected through feedstock bore 20. In this embodiment, filler 110 is in particulate or powdered form and is entrained in a carrier gas, preferably one which is inert with respect to the materials sprayed. Flame front 112 and a low pressure region 114 are shown in throat 18. After atomizing the molten metal tips of wires 78 and 80, a composite stream 115 is formed which impacts a target 116 to form a layer of abrasible material 118 in accordance with the present invention.

A number of fillers are suitable for use in forming the abrasible materials of the present invention. The most preferred filler for use herein is a plastics material. As used herein, the term "filler" shall be defined generally as follows: a material which is substantially physically and chemically thermally stable before the material is sprayed, during spraying in accordance with the present invention and in the service environment of the final abrasible material. Further, the preferred filler has a hardness value less than that of the material which is to be used to abrade the abrasible material, i.e. softer than the material of which the moving part that contacts the abrasible material is formed. Finally, the preferred filler is chemically stable with the matrix material during spraying in accordance with the present invention and during service of the abrasible coating. When the filler is supplied as a powder, it must also be flowable. Also, the preferred fillers used in the present invention are not significantly thermally degraded in the method of making the abrasible material. Although the filler is preferably provided in particulate form, such as, for example, a powder, it may also be in

rod form.

Therefore, in general, soft, friable fillers are preferred herein, and they may be either organic or inorganic. Particularly preferred fillers are synthetic polymers of the type used as plastics, fibres or elastomers. Natural polymers having the desired characteristics may also be suitable. Preferred synthetic polymers or copolymers include acrylic resins, such as, for example, polymers or copolymers of acrylic acid, methacrylic acid, esters of these acids, and acrylonitriles. Also preferred for use herein are bismaleimides produced by condensation of a diamine with maleic anhydride, for example by condensation of methylene dianiline with maleic anhydride; fluoroplastics such as, for example, polytetrafluoroethylene and polyvinylfluoride; wholly aromatic copolyesters such as, for example liquid crystalline polymers, for example those sold under the Registered Trade Marks Xydar (by Amoco Chemicals Corp.) and Vectra (by Hoechst Celanese); polyamide-imides, for example that sold under the Registered Trade Mark Torlon (by Amoco Chemicals Corp.); polyimides, both thermoplastic and thermoset; sulphone polymers, including polysulphones, polyarylsulphone and polyethersulphone; plastic polyesters such as for example aromatic polyesters, preferably polyarylates made from iso- and terephthalate with bisphenol aromatic homopolyester, polybutylene terephthalate, polyethylene terephthalate, wholly aromatic copolyester; silicone resin; epoxy resin; polyetheretherketone and polyphenylene sulphide. Generally, most thermoplastics and thermosets having the characteristics described are suitable for use in the present invention as the filler component. The thermoplastics and thermosets useful in the present invention encompass a broad range of molecular weights, for example from about 2000 to about 1,500,000. Values outside this range and monomers and prepolymers may also be suitable.

As stated, the filler used herein for the resultant abraded material should be soft and friable to produce an abrasible material having the desired characteristics. In addition to polymers, other non-metals preferably used as the filler component of the present invention include solid lubricant materials such, for example, boron nitride, calcium fluoride, molybdenum sulphide, fluorinated (non-graphitic) carbon, fluorinated graphite, non-graphitic carbon and graphite and combinations thereof.

Some soft ceramic materials are also suitable as a filler material, such as, for example, calcium carbonate; clays such as, for example, kaolin and bentonite; calcium phosphates; wollastonite; pyrophyllite; perlite; gypsum; barite; hydrated alumina; silica; and diatomite, including calcined diatomite and combinations thereof. In general, most non-abrasive minerals which are not unduly har-

dened in the flame spray process are acceptable. In addition it may be suitable to utilize certain soft metals as the filler component in the present invention.

The filler of the preferred embodiment of the present invention is a powder, preferably having a particle size of from about 5 microns to about 100 microns, although diameters outside this range may be suitable in some applications. The most preferred filler powders have a particle diameter of between from about 15 to 70 microns. The filler powder should be flowable within the requirements of the spray apparatus and should have a fairly narrow size distribution, such that excessive fines or large particles are not present. The techniques used to produce these powders will be well-known by those skilled in the art.

As stated, the metal for the metal matrix of the abradable material of the present invention is supplied preferably as a wire, one end of which is positioned in the path of the stream of combustion gases in which the filler is entrained as shown in Figure 3 of the drawings. A single wire may be utilized with melting of the tip being achieved by the heat of the combustion gases. Alternatively, two wires as shown in Figure 3 may be used with or without striking an arc between the two wire tips. Where an arc is struck, two-wire arc electric heating melts the wire tips, providing the source of molten metal which is then atomized by the gaseous stream. Where two wires are used, they may be the same or different metals. Accordingly, the wire must be consumable by one of these means.

Metals which are suitable for use in the present invention in forming the metal matrix component of the inventive abradable material are preferably supplied in wire form. Preferred metals include aluminium and its alloys, such as, for example, aluminium 1100, 1350, and other 1XXX series; aluminium/copper alloys in the 2XXX series; aluminium/silicon alloys such as, for example, 4043, 4047, and other 4XXX series; aluminium/magnesium alloys such as, for example, 5356 and other 5XXX series; aluminium/magnesium/silicon alloys in the 6XXX series; and aluminium/titanium alloys. Also suitable are copper and its alloys including copper UNS C101000-C15735; copper/aluminium alloys such as, for example, UNS C60600-C64400 (aluminium bronze); copper/nickel alloys such as, for example, UNS C70100-C72500. Also suitable are nickel and its alloys, including nickel UNS NO2200, UNS NO2201, and UNS NO2205; nickel/copper alloys including UNS NO4400, UNS NO4404, and UNS NO4405; and nickel/chromium alloys such as, for example, UNS NO6003. Other metals which are suitable for use in forming the metal matrix of the inventive abradable coatings are nickel and/or cobalt-based superalloys and high-temperature or

corrosion-resistant alloys. Preferred are MCrAlX alloys, wherein M is Fe, Ni, Co, or combinations thereof; X is rare earth metal, including La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf and combinations thereof, or where X is Zr, Si and combinations thereof. Also preferred for use herein are intermetallic compounds, including the aluminides of Ni, Ti and the like. Also suitable are steels, including low-carbon, alloy, and stainless steel. Also acceptable are pure metals, including nickel, cobalt, iron, copper, aluminium, and any other metals which can be formed into wires.

The gauge of the wire is not critical, but will generally range from about 0.762 to about 6.35 mm (about 0.030 to about 0.25 inches) in diameter. Values outside this range may also be suitable. As the molten metal tips of the wires melt and are atomized, the wire or wires are advanced in the direction of the stream at a rate which provides a constant supply of atomized molten metal.

One of the many advantages provided by flame spray apparatus 10 is the ability to regulate the velocity at which a particulate filler is injected into the flame front. Unlike many devices, flame spray apparatus 10 permits independent regulation of particle injection rate, fuel gas flow rate, and oxidant gas flow rate. The feedstock particles; are injected into the flame front by an independent stream of an inert carrier gas. By allowing independent regulation of flow rates, turbulence in converging throat 18 is substantially reduced by maintaining the pressure of the carrier gas at a higher value than the fuel gas pressure, which increases particle velocities. The range of carrier gas pressure is preferably from about 275.8 to about 482.7 kPa (about 40 to about 70 psig), more preferably from about 344.7 to 413.7 kPa (about 50 to about 60 psig), and most preferably always greater than the pressure of fuel gas. Also, although the relative dimensions of outlets 33 and 41 shown in Figure 3 can vary widely, as stated, the inner diameter of feedstock supply tube 22 is generally considerably smaller than the cross-section of annular fuel passage 32 or annular oxidant passage 40. The ratio of the cross-sectional areas of feedstock supply bore 20 to spray passage 56 of barrel 14 is generally about 1 to 25 to reduce the likelihood of the filler particles contacting and adhering to the internal surface of barrel 14 during spraying. By maintaining the carrier gas pressure above about 344.7 kPa (about 50 psig), where the fuel gas pressure is from about 310.2 to 448.2 kPa (about 45 to 65 psig) and the oxidant gas pressure is from about 482.6 to 620.6 kPa (about 70 to 90 psig), a phenomenon referred to as spitting is prevented which occurs at lower carrier gas pressures. Spitting results from radial movement of particles which may adhere to conical wall 16 and is believed to occur

at lower carrier pressures due to increased turbulence. Thus, maintaining the carrier gas pressure at high values reduces turbulence.

As the filler particles move into converging throat 18, the thermal and kinetic energy of the particles substantially increase due to an exothermic continuous high velocity diffusion reaction. The energetic filler particles pass through converging throat 18 to form a collimated stream of high-energy particles which are propelled in a substantially straight line through passage 56 of barrel 14. As stated, there is also a reduction in turbulent radial movement of the spray particles. By providing a non-turbulent flow of gas into converging throat 18, and sustaining a continuous high-velocity diffusion reaction confined to converging throat 18, axial, substantially non-turbulent flow of the combustion gases and the filler particles is achieved, which results in a high-velocity collimated particle stream. Also, as the particle stream passes through barrel 14, spreading of the stream is reduced by removing heat from barrel wall 46 with heat exchange jacket 58. By cooling barrel 14 in this manner, a thermal pinch is created which further reduces any radial movement of the energized particles toward the side walls of barrel 14.

As the collimated particle stream exits barrel 14, it passes through arc zone 82. During this passage, wires 78 and 80 are electrically energized in the most preferred embodiment to create a sustained electric arc between the ends of the wires. A voltage sufficient to sustain an arc between the ends of wires 78 and 80 is maintained by a suitable power supply (90). A voltage between about 15 and about 30 volts is generally sufficient. As molten metal forms at the wire ends, the particle stream atomizes the molten metal. To maintain the electric arc and, as stated, to provide a continuous supply of molten metal to the spray stream, wires 78 and 80 are advanced at a predetermined rate. As the molten metal is atomized, a combined or composite particle stream stream 115 is formed which contains both the filler and the atomized molten metal. Although some turbulence is created by the presence of wires 78 and 80, the composite particle stream maintains good collimation. The composite stream is then directed to target 116 where it forms the abradable material 118 of the present invention.

The metal matrix of the resultant coating in a typically preferred commercial abradable seal preferably comprises from about 40% to about 95% by volume of the abradable coating with the filler component comprising from about 5% to about 60% by volume of the abradable material. In a specific application, the method of the present invention is used to form an abradable coating on the surface of a part. In a most preferred embodiment, the

present invention comprises forming an abradable seal for a moving part, such as an abradable seal for turbine engines. In this aspect, the method of the present invention is utilized to form an abradable coating on the inner surface of a turbine engine shroud. Once the coating is solidified, the turbine engine blades are rotated to cut grooves into the abradable coating to form a well-fitted abradable seal.

The following Example more fully describes the present invention.

EXAMPLE

Using a spray gun substantially shown in Figures 1 to 3 of the accompanying drawings, an abradable material was formed as follows: two wires of aluminium 1100 having 1.59 mm (1/16 inch) diameters were fed at a rate of 34.5 grams/minute into the spray stream. The filler component was a thermoplastic polyimide which was fed axially into the combustion gas stream in the manner described above at a rate of about 15g/min. The thermoplastic powder size was substantially between 45 and 106 μm (-140 + 325 mesh). The oxidant gas was substantially pure oxygen at a flow rate of 225 litres/minute. Propylene was used as the fuel gas at a flow rate of 46 litres/minute. Two powder carrier gases were tested, nitrogen at 85 litres/minute and carbon dioxide at 67 litres/minute. The distance between the target and the gun as measured from the arc zone was approximately 29.2 cm (11.5 inches). The combustion gas velocity was approximately sonic. The resultant abradable material is shown in cross-section at Figure 4 which is a photomicrograph.

Claims

1. A method for making an abradable material which comprises axially feeding a filler into a stream of high-temperature combustion gases to entrain the filler in the stream of high-temperature combustion gases; atomizing a molten metal with the stream of high-temperature combustion gases having the entrained filler such that the atomized molten metal is entrained in the stream of high-temperature combustion gases along with the filler; directing the stream of high-temperature combustion gases having the entrained filler and the entrained atomized molten metal towards a target; the filler and the atomized metal entrained in the stream of high-temperature combustion gases forming a deposit on the target, the deposit comprising an abradable material having a metal matrix in which the filler is embedded.

2. A method according to claim 1, wherein the stream of combustion gases is formed in a combustion spray gun at supersonic velocity.
3. A method according to claim 1 or 2, wherein the filler is in particulate form.
4. A method according to any of claims 1 to 3, wherein the molten metal is supplied by placing the tip of at least one metal wire in the stream of high-temperature combustion gases having the entrained filler such that the metal wire tip is melted by the combustion gases.
5. A method according to any of claims 1 to 3, wherein the molten metal is supplied by providing two metal wires and means for supplying an electrical current to the metal wires, and establishing an electric arc between the tips of the wires, the electric arc being sufficient to melt the tips of the metal wires.
6. A method according to any of claims 1 to 5, wherein the filler is synthetic polymer powder selected from thermosetting polymers, thermoplastic polymers and combinations thereof.
7. A method according to any of claims 1 to 5, wherein the filler is a powder of a solid lubricant material selected from boron nitride, calcium fluoride, molybdenum sulphide, fluorinated non-graphitic carbon, fluorinated graphite, non-graphitic carbon, graphite, and combinations thereof.
8. A method according to any of claims 1 to 5, wherein the filler is a ceramic powder selected from calcium carbonate, kaolin, bentonite, calcium phosphate, wollastonite, pyrophyllite, perlite, gypsum, barite, hydrated alumina, silica, diatomite, calcined diatomite and combinations thereof.
9. A method according to any of claims 1 to 8, wherein the filler is supplied as a rod.
10. A method according to any of claims 1 to 9, wherein the molten metal is selected from aluminium, aluminium/silicon alloys, aluminium/magnesium alloys, aluminium/magnesium/silicon alloys, aluminium/titanium alloys, copper, copper/aluminium alloys, copper/nickel alloys, nickel, nickel/copper alloys, nickel/chromium alloys, cobalt-based superalloys, and combinations thereof.
11. A method according to any of claims 1 to 9, wherein the molten metal is a MCrAlX alloy, wherein X is selected from the rare earth metals, Y, Hf, Zr, and Si, and M is selected from Fe, Ni, Co and combinations thereof.
12. A method according to any of claims 1 to 9, wherein the molten metal is selected from nickel aluminides and titanium aluminides.
13. A method according to any of claims 1 to 9, wherein the molten metal is selected from low-carbon steel, alloy steel and stainless steel.
14. A method according to any of claims 1 to 9, wherein the molten metal is selected from the pure metals nickel, cobalt, iron, copper, aluminium, and combinations thereof.
15. A method according to any of claims 1 to 5 and 9, wherein the filler is a plastics material and the metal is selected from copper and copper alloys.
16. A method according to claim 1, wherein the filler is a particulate filler feedstock, the stream of high-temperature combustion gases into which the particulate filler feedstock is fed flows through a spray gun, the metal is in the form of metal wire and one end of at least one such metal wire is atomised by placing said one end in the path of the stream of high-temperature combustion gases, and the target to which the stream of high-temperature combustion gases having the entrained particulate filler feedstock and the atomised molten metal is directed is a surface whereupon a coating is formed in which the interstices of the metal matrix are filled with the particulate filler feedstock.
17. A method according to claim 1, wherein the filler is a powdered filler feedstock, the stream of high-temperature combustion gases is a stream of rapidly expanding high-temperature, high velocity combustion gases and the powdered filler feedstock is introduced thereinto in a spray gun, the metal in the form of at least one metal wire and the stream of high-combustion gases carrying the powdered filler feedstock is directed at the tip of the metal wire to atomise the metal, and the target to which the stream of high-temperature combustion gases having entrained therein the powdered filler feedstock and the atomised molten metal is directed, is a surface upon which is formed an abradable composite coating which surface serves as an abradable seal.

Patentansprüche

1. Verfahren zur Herstellung eines Verschleissmaterials, welches folgende Schritte umfasst:
 - axiales Zuführen eines Füllstoffs in einen Strom von Verbrennungsgasen hoher Temperatur, um den Füllstoff im Strom der Verbrennungsgase hoher Temperatur mitzureissen; 5
 - Zerstäuben eines geschmolzenen Metalls mittels des Stroms der Verbrennungsgase hoher Temperatur, welche den mitgerissenen Füllstoff enthalten, so dass das zerstäubte geschmolzene Metall im Strom der Verbrennungsgase hoher Temperatur zusammen mit dem Füllstoff mitgerissen wird; 10
 - Richten des Stroms der Verbrennungsgase hoher Temperatur, welcher den mitgerissenen Füllstoff und das mitgerissene, zerstäubte, geschmolzene Metall enthält, auf ein Zielobjekt; 15
 - Bildung einer Ablagerung aus dem vom Strom der Verbrennungsgase hoher Temperatur mitgerissenen Füllstoff und zerstäubten Metall auf dem Zielobjekt, wobei die Ablagerung ein Verschleissmaterial umfasst, welches eine Metallmatrix aufweist, in die der Füllstoff eingebettet ist. 20
2. Verfahren nach Anspruch 1, bei welchem der Strom des Verbrennungsgases in einer Verbrennungs-Sprühpistole bei Überschallgeschwindigkeit gebildet wird. 25
3. Verfahren nach Anspruch 1 oder 2, bei welchem der Füllstoff in Teilchenform vorliegt. 30
4. Verfahren nach einem der Ansprüche 1 bis 3, bei welchem das geschmolzene Metall dadurch zugeführt wird, dass die Spitze mindestens eines Metalldrahtes in den Strom der Verbrennungsgase hoher Temperatur, welcher den mitgerissenen Füllstoff enthält, plaziert wird, so dass die Metalldrahtspitze durch die Verbrennungsgase geschmolzen wird. 35
5. Verfahren nach einem der Ansprüche 1 bis 3, bei welchem das geschmolzene Metall dadurch zugeführt wird, dass zwei Metalldrähte und Mittel zum Anlegen eines elektrischen Stroms an die Metalldrähte vorgesehen werden und ein elektrischer Lichtbogen zwischen den Spitzen der Drähte erzeugt wird, wobei der elektrische Lichtbogen ausreichend ist, um die Spitzen der Metalldrähte zu schmelzen. 40
6. Verfahren nach einem der Ansprüche 1 bis 5, bei welchem der Füllstoff ein Pulver eines synthetischen Kunststoffs ist, ausgewählt aus wärmehärtbaren Kunststoffen, thermoplastischen Kunststoffen und Kombinationen davon. 45
7. Verfahren nach einem der Ansprüche 1 bis 5, bei welchem der Füllstoff ein Pulver eines festen Schmiermittels ist, ausgewählt aus Bornitrid, Calciumfluorid, Molybdänsulfid, fluoriertem, nicht-graphitischem Kohlenstoff, fluoriertem Graphit, nichtgraphitischem Kohlenstoff, Graphit und Kombinationen davon. 50
8. Verfahren nach einem der Ansprüche 1 bis 5, bei welchem der Füllstoff ein keramisches Pulver ist, ausgewählt aus Calciumcarbonat, Kaolin, Bentonit, Calciumphosphat, Wollastonit, Pyrophyllit, Perlit, Gips, Baryt, Tonerdehydrat, Siliciumdioxid, Diatomit, calciniertem Diatomit und Kombinationen davon. 55
9. Verfahren nach einem der Ansprüche 1 bis 8, bei welchem der Füllstoff in Stabform zugeführt wird.
10. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das geschmolzene Metall ausgewählt ist aus Aluminium, Aluminium/Silicium-Legierungen, Aluminium/Magnesium-Legierungen, Aluminium/Magnesium/Silicium-Legierungen, Aluminium/Titan-Legierungen, Kupfer, Kupfer/Aluminium-Legierungen, Kupfer/Nickel-Legierungen, Nickel, Nickel/Kupfer-Legierungen, Nickel/Chrom-Legierungen, Superlegierungen auf Cobalt-Basis und Kombinationen davon.
11. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das geschmolzene Metall eine Legierung der Formel $MCrAlX$ ist, worin X ausgewählt ist aus den Seltene-Erden-Metallen, Y, Hf, Zr und Si, und M ausgewählt ist aus Fe, Ni, Co und Kombinationen davon.
12. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das geschmolzene Metall ausgewählt ist aus Nickelaluminiden und Titanaluminiden.
13. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das geschmolzene Metall ausgewählt ist aus kohlenstoffarmem Stahl, Legierstahl und rostfreiem Stahl.
14. Verfahren nach einem der Ansprüche 1 bis 9, bei welchem das geschmolzene Metall ausgewählt ist aus den reinen Metallen Nickel, Co-

balt, Eisen, Kupfer, Aluminium und Kombinationen davon.

15. Verfahren nach einem der Ansprüche 1 bis 5 und 9, bei welchem der Füllstoff ein Kunststoffmaterial ist und das Metall ausgewählt ist aus Kupfer und Kupfer-Legierungen.
16. Verfahren nach Anspruch 1, bei welchem
- der Füllstoff ein teilchenförmiges Füllstoff-Aufgabegut ist; 10
 - der Strom der Verbrennungsgase hoher Temperatur, in welchen das teilchenförmige Füllstoff-Aufgabegut eingegeben wird, durch eine Sprühpistole fließt; 15
 - das Metall in Form eines Metalldrahtes vorliegt und ein Ende mindestens eines solchen Metalldrahtes zerstäubt wird, indem das genannte eine Ende in den Weg des Stroms der Verbrennungsgase hoher Temperatur plaziert wird; und 20
 - das Zielobjekt, auf welches der Strom der Verbrennungsgase hoher Temperatur, welcher das mitgerissene teilchenförmige Füllstoff-Aufgabegut und das zerstäubte geschmolzene Metall enthält, gerichtet ist, eine Oberfläche ist, auf welcher die Ablagerung gebildet wird, in der die Zwischenräume der Metallmatrix mit dem teilchenförmigen Füllstoff-Aufgabegut gefüllt sind. 25 30
17. Verfahren nach Anspruch 1, bei welchem
- der Füllstoff ein pulverförmiges Füllstoff-Aufgabegut ist; 35
 - der Strom der Verbrennungsgase hoher Temperatur ein Strom von sich schnell ausdehnenden Verbrennungsgasen hoher Temperatur und hoher Geschwindigkeit ist; 40
 - das pulverförmige Füllstoff-Aufgabegut mittels einer Sprühpistole und das Metall in Form mindestens eines Metalldrahtes eingeführt wird und der Strom der Verbrennungsgase hoher Temperatur, welcher das pulverförmige Füllstoff-Aufgabegut mitführt, auf die Spitze des Metalldrahtes gerichtet ist, um das Metall zu zerstäuben; und 45
 - das Zielobjekt, auf welches der Strom der Verbrennungsgase hoher Temperatur, welcher das mitgerissene pulverförmige Füllstoff-Aufgabegut und das zerstäubte geschmolzene Metall enthält, gerichtet ist, eine Oberfläche ist, auf welcher eine abtragbare zusammengesetzte Schicht gebildet wird, deren Oberfläche als sich selbst einschleifende Dichtung 50 55

dient.

Revendications

1. Procédé de réalisation d'un matériau abrada-
ble, qui consiste à alimenter axialement une
charge dans un courant de gaz de combustion
à haute température de manière à entraîner la
charge dans le courant des gaz de combustion
à haute température ; à atomiser un métal
fondu avec le courant des gaz de combustion
à haute température comprenant la charge en-
traînée de telle sorte que le métal fondu atomi-
sé soit entraîné dans le courant des gaz de
combustion à haute température en même
temps que la charge ; à diriger le courant des
gaz de combustion à haute température com-
prenant la charge et le métal fondu atomisé
entraînés vers une cible ; la charge et le métal
atomisé entraînés dans le courant des gaz de
combustion à haute température formant un
dépôt sur la cible, le dépôt comprenant un
matériau abrada-ble comportant une matrice
métallique dans laquelle la charge est encas-
trée.
2. Procédé selon la revendication 1, dans lequel
le courant des gaz de combustion est produit
dans un pistolet pulvérisateur à une vitesse
supersonique.
3. Procédé selon l'une des revendications 1 ou 2,
dans lequel la charge est sous forme parti-
culaire.
4. Procédé selon l'une quelconque des revendi-
cations 1 à 3, dans lequel le métal fondu est
fourni en plaçant l'extrémité d'au moins un fil
métallique dans le courant des gaz de com-
bustion à haute température comprenant la
charge entraînée, de telle sorte que l'extrémité
du fil métallique soit fondue par les gaz de
combustion.
5. Procédé selon l'une quelconque des revendi-
cations 1 à 3, dans lequel le métal fondu est
réalisé à partir de deux fils métalliques qui
sont alimentés en courant électrique et en éta-
blissant un arc électrique entre les extrémités
des deux fils, l'arc électrique étant suffisant
pour fondre les extrémités des deux fils métal-
liques.
6. Procédé selon l'une quelconque des revendi-
cations 1 à 5, dans lequel la charge est un
polymère synthétique en poudre, choisi parmi
les polymères thermodurcissants, les polymè-
res thermoplastiques et leurs combinaisons.

7. Procédé selon l'une quelconque des revendications 1 à 5, dans lequel la charge est une poudre d'un matériau lubrifiant solide, choisi parmi le nitrure de bore, le fluorure de calcium, le sulfure de molybdène, le carbone fluoré non-graphité, le graphite fluoré, le carbone non-graphité, le graphite et leurs mélanges. 5
8. Procédé selon l'une quelconque des revendications 1 à 5, dans lequel la charge est une poudre céramique choisie parmi les carbone de calcium, kaolin, bentonite, phosphate de calcium, wollastonite, pyrophyllite, perlite, gypse, baryte, aluminat hydraté, silice, diatomite, diatomite calcinée et leurs combinaisons. 10 15
9. Procédé selon l'une quelconque des revendications 1 à 8, dans lequel la charge est fournie sous forme de tige. 20
10. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le métal fondu est choisi parmi l'aluminium, les alliages d'aluminium/silicone, les alliages d'aluminium/magnésium, les alliages d'aluminium/magnésium/silicium, les alliages d'aluminium/titane, le cuivre, les alliages de cuivre/aluminium, les alliages de cuivre/nickel, le nickel, les alliages nickel/cuivre, les alliages nickel/chrome, les supers alliages à base de cobalt, et leur combinaisons. 25 30
11. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le métal fondu est un alliage MCrAlX, dans lequel X est choisi parmi les métaux des terres rares, Y, Hf, Zr et Si ; et M est choisi parmi Fe, Ni, Co et leurs combinaisons. 35
12. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le métal fondu est choisi parmi les aluminures de nickel, les aluminures de titane. 40
13. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le métal fondu est choisi parmi l'acier faiblement carburé, l'alliage d'acier et l'acier inoxydable. 45
14. Procédé selon l'une quelconque des revendications 1 à 9, dans lequel le métal fondu est choisi parmi les métaux purs de nickel, cobalt, fer, cuivre, aluminium et leurs combinaisons. 50
15. Procédé selon l'une quelconque des revendications 1 à 5 et 9, dans lequel la charge est une matière plastique et le métal est choisi parmi le cuivre et les alliages de cuivre. 55
16. Procédé selon la revendication 1, dans lequel la charge est un substrat de charge particulière, le courant des gaz de combustion à haute température dans lequel le substrat de charge particulière est amené, s'écoule à travers un pistolet pulvérisateur, le métal est sous la forme d'un fil métallique dont au moins une extrémité est atomisée en la plaçant dans le trajet du courant des gaz de combustion à haute température, et la cible sur laquelle est dirigé le courant des gaz de combustion à haute température comprenant le substrat de charge particulière entraîné et le métal fondu atomisé est une surface sur laquelle un revêtement est formé et dans lequel les interstices de la matrice de métal sont remplis par le substrat de charge particulière.
17. Procédé selon la revendication 1, dans lequel la charge est un substrat de charge en poudre, le courant des gaz de combustion à haute température est un courant de gaz de combustion à grande vitesse et à température élevée progressant rapidement, et le substrat de charge en poudre est introduit à l'intérieur du pistolet pulvérisateur, le métal qui est sous la forme d'au moins un fil métallique, le courant des gaz de combustion à haute température portant le substrat de charge en poudre étant dirigé sur l'extrémité du fil métallique pour atomiser le métal, la cible sur laquelle est dirigé le courant des gaz de combustion à haute température comprenant le substrat de charge en poudre et le métal fondu atomisé étant une surface sur laquelle est formé un revêtement composite abrasable, ladite surface étant utilisable en tant que garniture abrasable.

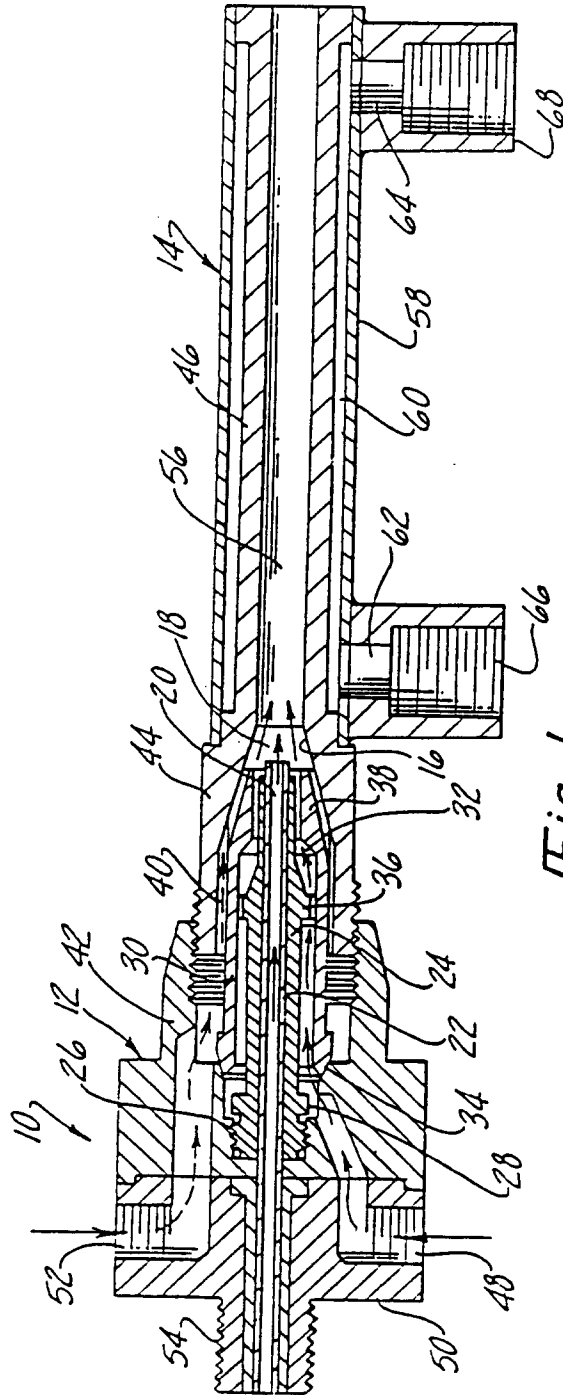
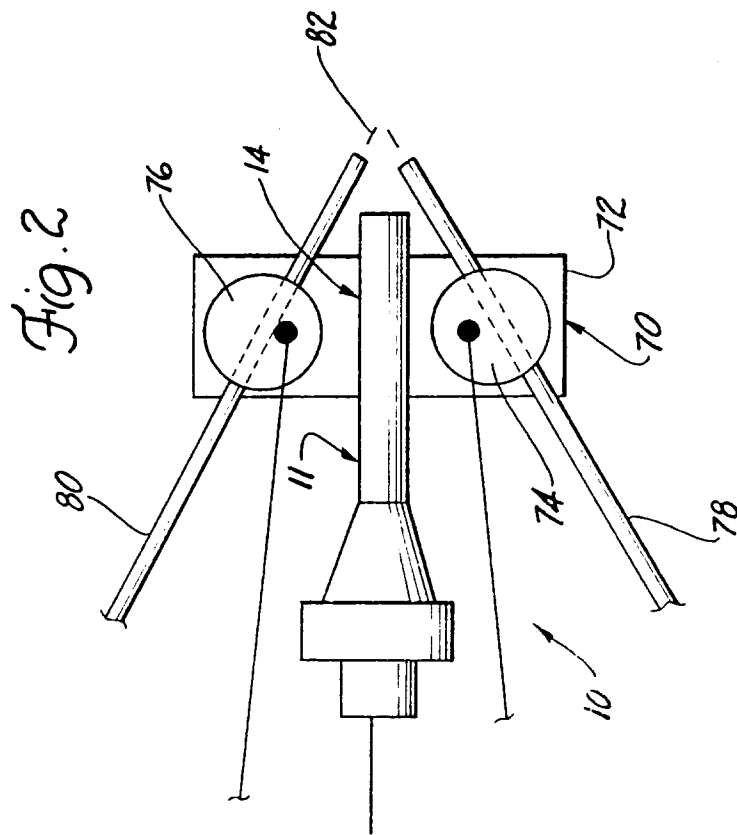


Fig-1



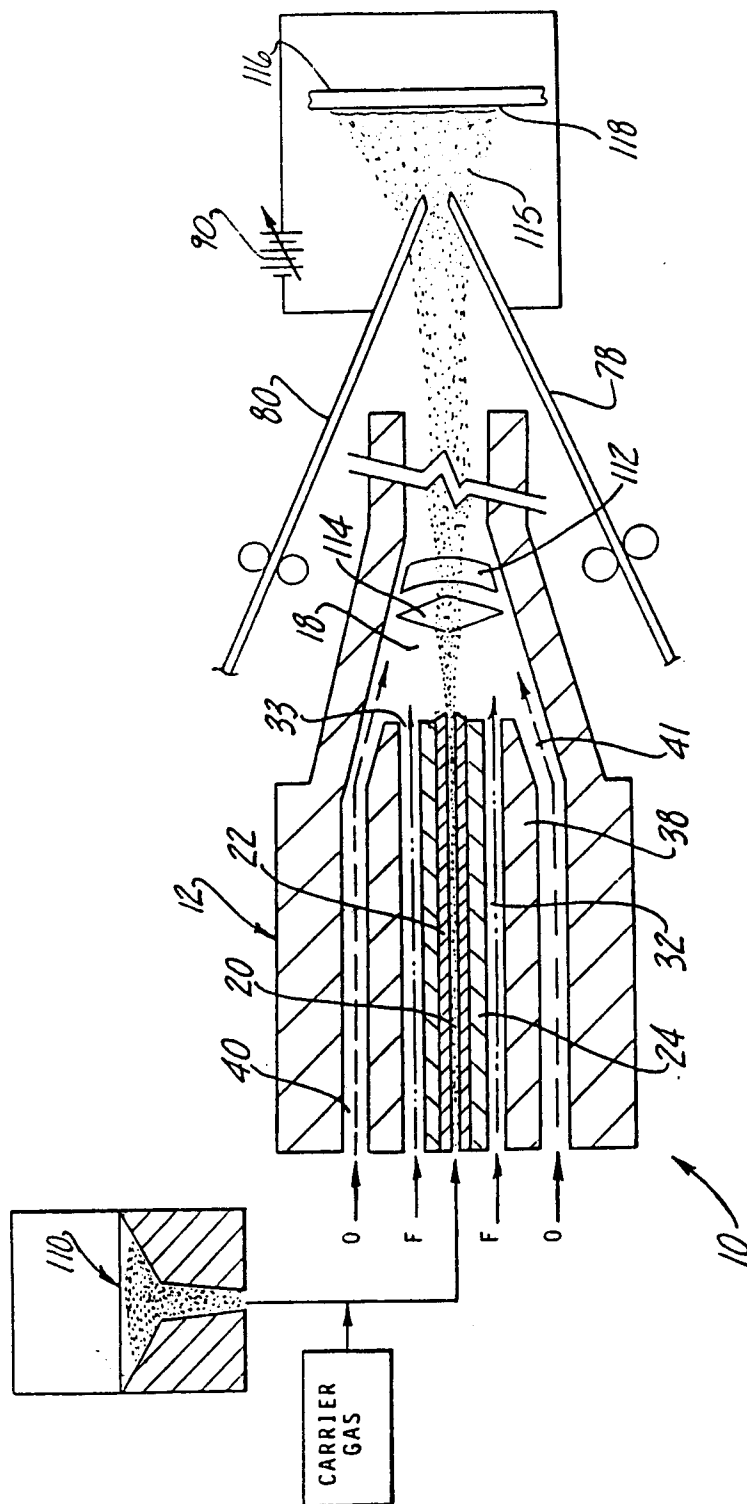


Fig. 3

Fig. 4

