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(54) OUTER AIRSEAL ABRADABLE RUB STRIP MANUFACTURE METHODS AND APPARATUS

(57) A method for applying an abradable coating, for example to a blade outer airseal (BOAS) substrate, comprises: generating a plasma (15); introducing a matrix-forming first particulate (23) to the plasma (15) at a first location; introducing a second particulate (25) of an organic particulate and/or salt particulate to the plasma (15) at a second location downstream from the first location to mix with the matrix-forming first particulate (23), the second particulate (25) having a characteristic size in the range 6.0 micrometers to 45.0 micrometers; and directing the first particulate (23) and the second particulate (25) to a target (10) to form a coating on the target (10).

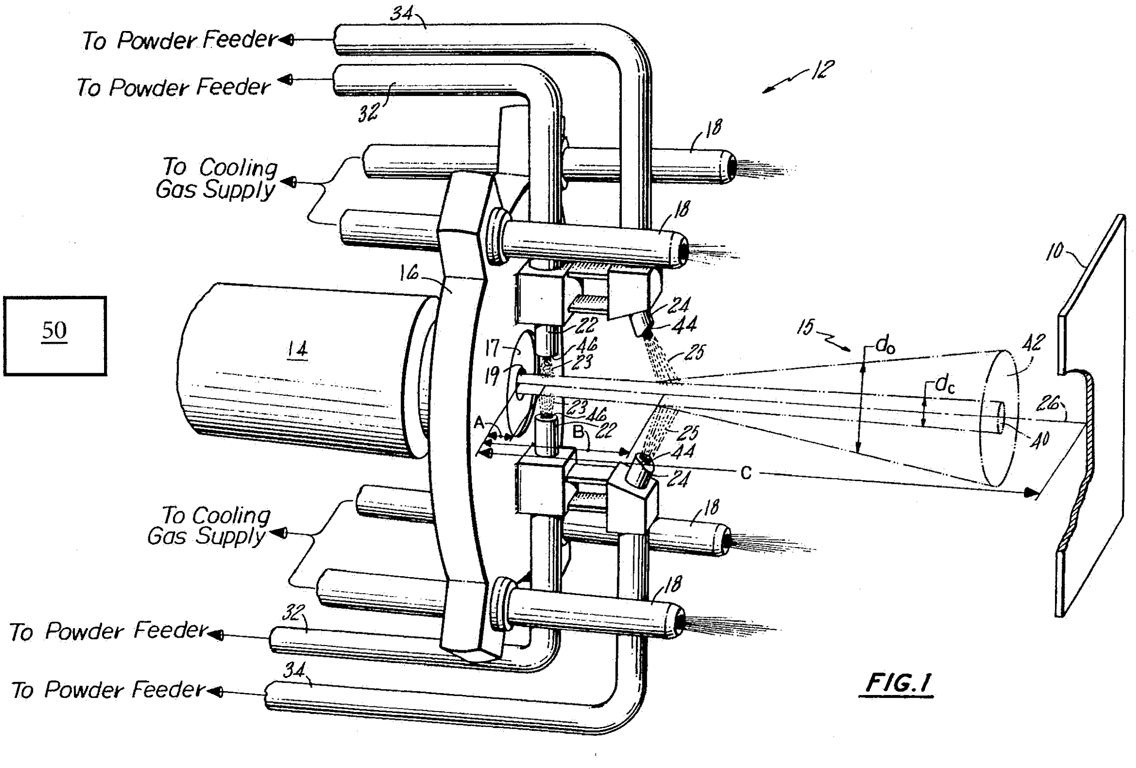

FIG.1

EP 3 276 039 A1

Description

BACKGROUND

[0001] This disclosure relates to a gas turbine engine, and more particularly to gaspath leakage seals for gas turbine engines.

[0002] Gas turbine engines, such as those used to power modern commercial and military aircraft, generally include one or more compressor sections to pressurize an airflow, a combustor section for burning hydrocarbon fuel in the presence of the pressurized air, and one or more turbine sections to extract energy from the resultant combustion gases. The airflow flows along a gaspath through the gas turbine engine.

[0003] The gas turbine engine includes a plurality of rotors arranged along an axis of rotation of the gas turbine engine. The rotors are positioned in a case, with the rotors and case having designed clearances between the case and tips of rotor blades of the rotors. It is desired to maintain the clearances within a selected range during operation of the gas turbine engine as deviation from the selected range can have a negative effect on gas turbine engine performance. For each blade stage, the case typically includes an outer airseal located in the case immediately outboard (radially) of the blade tips to aid in maintaining the clearances within the selected range.

[0004] Within the compressor section(s), temperature typically progressively increases from upstream to downstream along the gaspath. Particularly, in relatively downstream stages, heating of the airseals becomes a problem. US Patent Application No. 14/947,494, of Leslie et al., entitled "Outer Airseal for Gas Turbine Engine", and filed November 20, 2015 ('494 application), discusses several problems associated with heat transfer to outer airseals and several solutions.

[0005] The airseal typically has an abradable coating along its inner diameter (ID) surface. In relatively downstream stages of the compressor where the blades have nickel-based superalloy substrates, the abradable coating material may be applied to a bondcoat along the metallic substrate of the outer airseal. For relatively upstream sections where the compressor blades comprise titanium-based substrates (a potential source of fire) systems have been proposed with a fire-resistant thermal barrier layer intervening between the bondcoat and the abradable material. An example of such a coating is found in US Patent No. 8,777,562 of Strock et al., issued July 15, 2014, and entitled "Blade Air Seal with Integral Barrier".

[0006] US Patent, 8,562,290 of Strock et al. issued October 22, 2013, and entitled "Blade outer air seal with improved efficiency", discloses abradable material comprising a matrix of an alloy and a fine hexagonal boron nitride (hBN) containing particles of a coarser hBN. A first thermal spray feedstock comprise agglomerates of alloy particles and fine hBN particles agglomerated using polyvinyl alcohol. The coarse hBN may be from a second spray feedstock.

[0007] Among coating application techniques are thermal spray processes such as air plasma spray. Typically, the plasma spray process involves a single feedstock outlet discharging a mixture of coating constituents and fugitive porosity former in to a plasma jet. Proposals have been made to segregate the porosity former and introduce that through a relatively downstream outlet while the matrix and solid lubricant are introduced from a conventionally located upstream outlet. Examples of these are found in US Patent 4696855, of Petit, Jr. et al., issued September 29, 1987, and entitled "Multiple Port Plasma Spray Apparatus and Method for Providing Sprayed Abradable Coatings", and US Patent 4299865, of Clingman et al., issued November 10, 1981 and entitled "Abradable Ceramic Seal and Method of Making Same". US Patent 4386112, of Eaton et al., issued May 31, 1983, and entitled "Co-Spray Abrasive Coating" shows separate introduction of matrix and abrasive in an abrasive coating.

SUMMARY

[0008] One aspect of the disclosure involves a method for applying an abradable coating. The method comprises: generating a plasma; introducing a matrix-forming first particulate to the plasma at a first location; introducing a second particulate of an organic particulate and/or salt particulate to the plasma at a second location downstream from the first location to mix with the matrix-forming first particulate, the second particulate having a characteristic size in the range 6.0 micrometers to 45.0 micrometers; and directing the first particulate and the second particulate to a target to form a coating on the target.

[0009] An embodiment may additionally and/or alternatively include removing the second particulate from the coating so as to leave porosity.

[0010] A further embodiment may additionally and/or alternatively include the second particulate characteristic size being a D50 size.

[0011] A further embodiment may additionally and/or alternatively include the D50 size being 15 micrometers to 35 micrometers.

[0012] A further embodiment may additionally and/or alternatively include the second particulate having a D90 size of at most 45 micrometers.

[0013] A further embodiment may additionally and/or alternatively include the first particulate having metallic particles of D50 particle size of 11-90 micrometers.

[0014] A further embodiment may additionally and/or alternatively include the metallic particles comprising Cu-Ni alloy or an MCrAlY.

[0015] A further embodiment may additionally and/or alternatively include the first particulate being an agglomerate of said metallic particles and particles of an inorganic non-metallic filler.

[0016] A further embodiment may additionally and/or alternatively include the second particulate being introduced at a volume flow rate of 40% to 80% of a total particulate flow rate.

[0017] A further embodiment may additionally and/or alternatively include the second location being at least 0.30 inch (7.62 mm) downstream of the first location.

[0018] A further embodiment may additionally and/or alternatively include the first location being within 2.0 diameters of a nozzle downstream of the nozzle outlet.

[0019] A further embodiment may additionally and/or alternatively include the second location being at least 3.0 diameters downstream of the nozzle outlet.

[0020] A further embodiment may additionally and/or alternatively include the second location being at least 0.60 inch (15.24 mm) downstream of a nozzle outlet.

[0021] A further embodiment may additionally and/or alternatively include both the first particulate and the second particulate being injected into a core of the plasma.

[0022] A further embodiment may additionally and/or alternatively include the coating being applied to a blade outer airseal substrate.

[0023] A further embodiment may additionally and/or alternatively include the coating having Vickers micro-hardness of a coating cross-section of not more than 400 measured with a 50g load in a location when 100 randomly located indents are made on the cross-section.

[0024] A further embodiment may additionally and/or alternatively include the coating having a cohesive bond strength of 750 psi (5.17 MPa) to 2000 psi (13.8 MPa).

[0025] From another aspect, the invention provides a blade outer airseal coated by the method.

[0026] Another aspect of the invention involves a method for applying an abradable coating. The method comprises: generating a plasma; introducing a matrix-forming first particulate to the plasma at a first location; introducing a second particulate of a fugitive porosity-former to the plasma at a second location downstream from the first location to mix with the matrix-forming first particulate, the second particulate fugitive-former having a characteristic size in the range 6.0 micrometers to 45.0 micrometers; directing the first particulate and the second particulate to a target to form a coating on the target; and removing the fugitive porosity-former from the coating.

[0027] The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a view of a plasma spray apparatus.

DETAILED DESCRIPTION

[0029] US Patent 4299865 identifies downstream introduction (injection) of polyester porosity former at -140 +325 Mesh (44-105 micrometers). US Patent 4696855 also discloses downstream injection.

[0030] FIG. 1 shows a substrate 10 to be coated and the apparatus 12 used to deposit the powders onto the substrate. The exemplary apparatus is based on that of US Patent 4696855; however other baselines may be used. Not shown in the Figure, but part of the spray system, may be the powder supply means (powder hoppers, carrier gas sources, valves and the like); means for moving the substrate 10 and the apparatus 12 relative to each other (e.g., six-axis robot carrying the gun and a similar robot or manipulator carrying the substrate) are also not shown. The specific manner in which the substrate 10 and apparatus 12 are moved will depend on the nature of the substrate. Either the substrate 10 may be moved while the apparatus 12 is kept in a fixed position, the apparatus 12 moved while the substrate 10 is kept in a fixed position, or the substrate 10 and apparatus 12 both moved. Exemplary substrates are metallic (e.g., nickel-based superalloy) and/or of components such as blade outer airseals (BOAS). Alternative substrates include those of bearing compartment knife edge seal mating surfaces, plate seals (axial) and the inner diameter (ID) of vanes which have seals that are cut by knife edges on a rotor.

[0031] The apparatus 12 includes a gun assembly 14. For purposes of this discussion, the gun assembly 14 is of the plasma arc type. In a typical plasma arc gun assembly 14, a high temperature electric arc is generated between spaced apart electrodes. Primary and secondary gases, e.g., helium, argon, or nitrogen, or mixtures thereof, pass through the arc, and are ionized to form a high temperature, high velocity plasma plume or stream 15 which extends in a downstream direction from the gun nozzle 19 towards the substrate 10. In order to withstand the high temperature of the plasma stream 15, the gun nozzle 19 (plasma nozzle) is typically water cooled.

[0032] A fixturing bracket 16 is attached to the front end 17 of the gun assembly 14 by means not shown in the Figure. Attached to the bracket 16 are nozzles 18 which each spray a stream of cooling gases onto the substrate 10 to prevent the substrate 10 from being excessively heated by the plasma stream 15. Useful cooling gases include, e.g., nitrogen, argon, and/or air. As is discussed in more detail below, powder ports 22, 24 are arranged to direct separate streams of powder particles into the plasma stream 15. First powder ports 22 (shown as an opposed pair, but optionally a single port at a single circumferential location) direct particles of a first type of powder 23 into the stream 15, and second powder ports 24 (shown as an opposed pair, but optionally a single port at a single circumferential location) direct particles of a second type of powder 25 into the stream 15.

[0033] FIG. 1 shows two first powder ports 22 about 180° from each other, and two second powder ports 24 about 180° from each other, and generally radially aligned with the position of the first powder ports 22. However, the number of powder ports 22, 24, and their relative position may vary. The first powder ports 22 are axially upstream of the second powder ports 24, and are constructed and arranged to inject the first powder particles 23 into the stream 15 at a distance A from the front end 17 of the gun assembly 14; the second powder ports 24 inject the second powder particles 25 into the stream 15 at a downstream distance B. The distance between the gun front end 17 and the substrate 10 is designated C.

[0034] US Patent 4696855 states that, as a result of a selected arrangement of the first and second powder ports 22, 24, and the rate and velocity in which the powder particles 23, 25 are separately injected into the stream 15, there is little mixing of the particles 23, 25 in the stream 15. Furthermore, the residence or dwell time of the second powder particles 25 in the plasma stream 15 is less than the dwell time of the first powder particles 23.

[0035] As is discussed below, when the second particles 25 are of a fine fugitive porosity former that reduced dwell time may presently be desired to maintain the particles in a fine state. However improved mixing may be desirable. Thus, the drawing reflecting the layout taken from US Patent 4696855 may not be to scale as proportions are varied to achieve improved mixing rather than avoid it.

[0036] As in US Patent 4696855, powder particles 23, 25 are delivered to the powder ports 22 and 24 by lines 32 and 34, respectively. The lines 32, 34 are pressurized with a carrier gas which is typically argon. The two feed lines 32 are each connected to a separate powder feeder which contain the first powder particles 23 and the two feed lines 34 are each connected to a separate powder feeder which contain the second powder particles 25. All powder feeders are independently controllable (e.g., via a microprocessor-based controller 50) to deliver powder at a specified rate and velocity to and through their respective powder ports.

[0037] The plasma stream 15 spreads radially outwardly from the stream axis 26 as the downstream distance from the gun front end 17 increases. The resulting overall shape of the stream 15 is similar to that of a tapered cylinder. Observations have indicated that the plasma stream 15 actually comprises a central stream of moving gases 40 and a radially outer, peripheral stream of moving gases 42. The central stream 40 represents a core and the peripheral stream 42 is believed to represent a turbulent boundary layer cooler than the core due to mixing. The diameter d_c of the central stream 40 increases only slightly as the downstream distance increases, while the diameter do of the outer stream 42 increases to a much greater extent as the downstream distance increases. The temperature as well as the velocity of the gases within the central plasma stream 40 is considerably higher than the temperature and velocity of the gases in the outer stream 42.

[0038] The operating parameters of each first powder feeder are selected to inject a substantially continuous flow of powder particles of the first powder type (e.g., agglomerate of metallic matrix and solid lubricant or other non-fugitive filler) through its respective first powder port 22 and directly into the central stream of gases 40. The first powder particles 23 are carried by the central stream 40 until they impact upon the substrate 10. Tests have shown that there is little radial deviation of the first powder particles 23 outside of the central stream 40, apparently due to their relatively high axial momentum in the stream 15, although other forces may be acting to produce this effect.

[0039] As noted above, in distinction to US Patent 4696855, to improve mixing, rather than avoid it, the second powder particles 25 may be injected through the stream 42 and into the stream 40. Whereas the turbulence of the stream 42 is believed to cause uneven distribution of particles it might carry, by penetrating the introduction of the second powder particles in to the steam 40. A more even and mixed distribution with the first powder is achieved.

[0040] As is seen in FIG. 1, the outlet end 44 of each of the second powder ports 24 is radially outward of, as well as axially downstream of, the outlet end 46 of each of the first powder ports 22. In the baseline US Patent 4696855, the operating parameters of each second powder feeder are selected to inject the second powder particles 25 into the plasma stream 15 such that they do not enter the central stream of gases 40. Rather, the second powder particles 25 are carried by the outer stream of gases 42 until they impact upon the substrate 10. Whether the different powder particles 23, 25 are properly injected into their respective plasma stream portion 40, 42 and are carried by such stream portion to the substrate 10, can be determined by evaluating the distribution of the powder particles 23, 25 in the stream 15.

[0041] In a present modification of the operation of baseline US Patent 4696855, outer stream of gas 42, forms a low temperature turbulent layer around the central stream of hot gases 40.It is desirable to inject the first powder particles

23 and second powder particles 25 through the outer gas stream to be carried to the substrate 10 by gas stream 40. The particles 23 and 25 mix within the plasma stream 15. This is unlike prior art plasma spray processes, wherein the different powder types are deliberately injected into separate portions of the plasma stream to prevent mixing.

[0042] Use of downstream injection of the fugitive former expands the possible candidates for porosity formers. As is discussed below, substantially finer powders of polymer or other porosity formers may have one or more advantages. Downstream injection of the fugitive allows smaller and lower melting point or decomposition point fugitives to be used. It is more consistent and predictable to inject into the higher energy core gas stream 40 than injecting into the outer turbulent layer (because of the turbulence). Downstream injection into the core gas stream imparts more velocity and uniformity than would downstream injection into the outer turbulent layer. The downstream injection into the core gas steam may also replace a baseline upstream injection into the turbulent layer. Overheating the smaller particles is avoided by both. Downstream is cooler and the turbulent periphery is cooler. Downstream core injection has the advantage of not being turbulent and therefore has a more consistent influence on the particles.

[0043] In abradable coatings there are two primary categories of wear mechanisms: those that cause wear through the constituent particles; and fracture in and between the constituent particles. The latter is considered normal abradable wear. The fracture mechanism of constituent particle removal (splats and groups of splats) takes the lowest energy per unit volume of coating wear and results in low levels of blade heating and wear. The force at which these fractures take place are conventionally related to coating hardness and density.

[0044] Conventional wisdom says that the more fugitive, the lower the bulk hardness (HR15Y) and density, and the easier it is to break constituent particles out of the coating during rub against blades (bare or tipped blades). This ease of breaking out constituent particles is termed abradability. It is desirable to activate these spray particle (constituent or splat) liberation fracture mechanisms to prevent damage to blade tips and prevent blade metal transfer to the abradable. Abradable wear by liberation of coating constituent particles is a low specific energy process (i.e., fracture of the bonds between particles occurs to liberate coating material and limit contact pressure which is directly related to the frictional heating which softens the mating materials making them more susceptible to plastic deformation and material transfer mechanisms).

[0045] During detailed observation (e.g., via SEM) of rubbed abradable surfaces it has become apparent that the random assembly of constituent particles results in local areas with higher and lower concentration of metal matrix material. It has also been observed that those regions of relatively high metal content vary in size with larger and smaller areas of relatively high metal matrix concentration. After rub under relatively low radial incursion rates, these areas of high metal content have been associated with the onset of blade metal transfer.

[0046] Hardness testing on various macro and micro scales has been used as an indicator of this variation in constituent distribution. The conventionally used HR15Y scale for macro hardness measurement uses a 15kg load and measures a relatively large volume of coating. Within that volume there is microstructural variation in metal content (vs. porosity and non-metallic components). The local variations in metal content within that volume can be further characterized by micro indentation which uses a smaller indenter load (50 g) and indicates the properties of a proportionately smaller volume of coating.

[0047] As one would expect, microhardness within an area of higher metal content is higher (than in low-metal content regions and higher than that indicated by a macrohardness indentation that indicates the average influence of many higher and lower metal concentration regions). When doing microhardness indentation at 50g load Vickers hardness indentation, high variation was noticed.

[0048] Investigation into local property variation of the coating by microhardness indentation revealed that: (a) the areas of high metal concentration are much harder (stronger) than relatively smaller areas of high metal content; and (b) microhardness of the high metal concentration areas indicates a higher strength than indicated by a more macro hardness measurement. This is explained by the larger volume of coating material evaluated in macrohardness and the effective averaging of multiple high and low metal content regions with that volume.

[0049] The microhardness is taken to indicate the relative ease with which these constituent particles may be fractured from the coating by contact with the blade. It may thus be possible to improve abradability by reducing the hardness or strength of the larger high metal content regions without adversely affecting other coating performance characteristics such as erosion resistance. This may be done by reducing the size of the metal rich regions without changing the fugitive to matrix ratio.

[0050] By reducing fugitive particle size while maintaining overall volume fraction, a larger number of fugitive particles are used per volume of coating and therefore the average spacing between these fugitive particles is reduced. Furthermore, by reducing this average spacing, the size of the metal-rich areas are also reduced proportionally. With smaller metal-rich areas, there are less metal matrix particles connecting them to the rest of the coating and they are easier to break away during rub interaction. For example, if the diameter of the fugitive is reduced by half, the volume of a single particle is only 1/8th that of the original. This results in the number of fugitive particles per volume being increased by a factor of 8. This example reduces the average interparticle spacing by 50% and therefore also the average size of the metal-rich regions.

[0051] One example of fugitive is 15-30 micrometers with 22.5 micrometers nominal (e.g., D50) compared with a baseline of 60-120 micrometers or 90 micrometers nominal (e.g., a baseline slightly larger than the nominal of US Patent 4299865). This example has a diameter ratio of 4 which means that the average fugitive particle spacing would be reduced by a factor of 4 and the associated larger metal rich areas also reduced in thickness by a factor of 4.

[0052] As noted above candidate fugitive porosity formers (hereafter "fugitive") are not limited to polymers. Additional candidates are salt fugitives (e.g., chlorides, phosphates, nitrates, sulfates, and the like). Sodium chloride is one example. These may be subject to chemical decomposition or vaporization if introduced as fine powder in the conventional upstream injection location. The fugitive may be removed from the coating by one or more methods. One mechanism is the heating from running the engine. Other active steps include heating of coated parts after coating but before installation. Salt fugitive may be dissolved out via water immersion. In some applications involving cool components toward the front of the engine, organic material that would otherwise be a fugitive may be left in and not burned/vaporized out before service or even in service. Leaving in this material may improve aerodynamic efficiency. The material may be removed in a thin surface layer during low incursion rate rub events by the temperature rise associated with frictional heating by the blade tips. This removal along a shallow surface layer (1-25 microns) leaves porosity in that surface layer that provides a location for plastically smeared abradable matrix material to be deposited during wear while leaving lower regions filled to improve aerodynamic efficiency.

[0053] Characteristic fugitive particle size is 11-45 micrometers. This characteristic may be a D50 value or mass median diameter. Exemplary D50 are 11-35 micrometers, more particularly 15-35 micrometers or 11-25 micrometers. Exemplary D90 values are up to 45 micrometers, more narrowly, up to 35 micrometers. For example, it may be -325 mesh. Table I below shows several ranges. For a given row example further variants involve having only some of the values in the associated columns.

Table I

Fugitive Sizes				
Example/Range	Size (micrometers)			Mesh
	D50	D10	D90	
1	11-35	6	45	
2	15-35	6	45	
3	11-25	6	35	
4	22	11	33	
5	11-35	6		-325

[0054] Matrix material may be selected from current or future matrix alloys and sizes. Exemplary alloys include Cu-Ni alloys (e.g., Cu26Ni8.5A14Cr) or an MCrAlY (although the Y may be eliminated in lower temperature engine locations). Exemplary D50 particle size is 11-90 micrometers. The upper end of that range may be less desirable because larger particles contribute to larger islands of metal matrix material and have been associated with increased blade wear. Thus, alternative D50 upper ends are 75 micrometers and 45 micrometers. An alternative lower (D10) end is 16 micrometers. Table II below shows several ranges. For a given row example further variants involve having only some of the values in the associated columns.

Table II

Matrix Sizes			
Example/Range	Size (micrometers)		
	D50	D10	D90
1	50	11	90
2	45	16	75
3	22	16	45
4	40-55	6-20	60-110
5	20-25	6-20	35-55

(continued)

Matrix Sizes			
Example/Range	Size (micrometers)		
	D50	D10	D90
6	35-50	11-20	60-90
7	11-90	>5	<120
8	20-50		

[0055] Exemplary persistent non-metallic filler ("soft filler") is selected to limit adhesion of metal particles and interfere with the smearing and material transfer often associated with rub interactions. As noted above, hBN is one example. Table III below shows several particle size ranges. For a given row example further variants involve having only some of the values in the associated columns.

Table III

Filler Sizes				
Example/Range	Size (micrometers)			Mesh
	D50	D10	D90	
1	11-35	6	45	
2	15-35	6	45	
3	11-25	6	35	
4	22	11	33	
5	11-35	6		-325

[0056] Exemplary proportions of the matrix and soft filler in the first powder source are 1 to 25 volume % as a percentage of the sum of soft filler and metal volume.

[0057] As noted above, these may be as agglomerates. Exemplary agglomerates are agglomerated with a fugitive agent such as polyvinyl alcohol at a volume percentage in the agglomerate of 1-5 volume %.

[0058] Table IV below shows several ranges. For a given row example further variants involve having only some of the values in the associated columns.

Table IV

Agglomerate Properties				
Example/Range	Size (micrometers)			Vol% filler
	D50	D10	D90	
1	75	16	125	1-25
2	45	16	90	5-15
3	22	11	75	5-15
4	45	16	75	7-12
5	35-45	11-22	55-100	3-15
6	20-80	10-25	50-140	1-25

[0059] The as-applied coating (prior to fugitive removal) may have an exemplary 20-35% by volume matrix and <10% porosity (preferably ≤5% in order to provide good bonding between metal particles; this allows a lower ultimate metal content for a given bulk strength and erosion resistance). Non-matrix components may represent the fugitive porosity former and soft fillers at combined content of 55% to 80% by volume. Exemplary soft filler content may be 0% to 15% by volume. Soft filler serves to prevent transfer of material (coating material shifted by the blades or material transferred from the blades themselves) by allowing release of that material. The fugitive may represent 40% to 80% by volume, more particularly, 60% to 75%. With approximately constant deposition efficiency, relative volume flow rates in the spray process may be similar to these relative volumes.

[0060] Exemplary ratios of the fugitive flow rate to the first powder in an air plasma spray process are 0.2 to 0.4 (by weight, with an example where the first powder has a theoretical density of 8.5 g/cc and the fugitive has a theoretical density of 1.2 g/cc).

[0061] In an exemplary implementation, the A value or distance will be of a similar magnitude to the nozzle diameter (e.g., up to about 3 times the nozzle diameter, with exemplary values of 0.5 to 2.0 or 0.5-1.5 and a nominal of about 0.75). This A value may represent the injection location of all material in a baseline spray apparatus being modified to add downstream injection of fugitive or other material.

[0062] The B value will be greater than the A value by any of several measures. Exemplary B may be at least twice the nozzle diameter or at least 3.0 times (e.g., 2.5-10.0 or 3.0-8.0). An exemplary separation (B-A) of the two introductions is at least the A value or the nozzle diameter, more particularly at least twice either or both of those amounts.

[0063] An exemplary nozzle diameter is 0.25 inch (6.35 mm). Thus, an exemplary separation (B-A) of the two introductions is at least 6 mm or at least 12 mm, with an exemplary range of 6 mm to 30 mm, more particularly, 8 mm to 25 mm. If, such as shown for the fugitive, an angled introduction is made, then the positions at which A or B may be measured may correspond to the intersections of the centerlines of the powder discharges with the plasma centerline. Table V below provides exemplary injection parameters. The basic example is the aforementioned 0.25 inch (6.35 mm) nozzle. Several variations reflect scaling.

Table V

Injection Parameters					
Parameter	Units	Ex. 1	Ex. 2	Ex. 3	Ex. 4
Nozzle Diameter	inch	0.250	0.354	0.250	0.354
	mm	6.35	9.00	6.35	9.00
Area	in^2	0.049	0.099	0.049	0.099
	cm^2	0.32	0.64	0.32	0.64
Arc Gas Flow Rate	SCFH	100	100	150	150
	in^3/s	48	48	72	72
	cm^3/s	310	310	465	465
Velocity at std. temp. and pressure (STP)	in/s	978	487	1467	730
	cm/s	2484	1236	3726	1855
Nominal B distance for injection	inches	1.00	0.71	1.22	0.86
	mm	25.4	17.9	31.1	21.9

[0064] In the table, standard temperature and pressure (STP) are a temperature of 273.15 K (0 °C, 32 °F) and an absolute pressure of exactly 100 kPa (1 bar, 14.504 psi, 0.98692 atm.). In variations of the examples, the B distance may be 20% greater or 40% greater than nominal or 20% less or 40% less.

[0065] The exemplary as-applied coating has a cohesive bond strength of 500-3000 psi (3.5-20.7 MPa), more particularly 750-2000 psi (5.2-13.8 MPa). Bond strength may be influenced/adjusted by: spray parameters (primary gas flow, secondary gas flow, nozzle size, power, standoff distance, and the like); composition (ratios described above). This bond strength is in the usual range for a desirable balance between erosion resistance and abradability at high interaction rates.

[0066] Target maximum Vickers micro-hardness of a coating cross section is 400 or more desirably 300 with a 50g load (in any location when 100 randomly located indents are made on the cross section). The test is performed with a sample infiltrated with epoxy mounting material. This affects the measurement, especially at the loosely connected areas, much less at the areas of interest where there is more metal.

[0067] The use of small fugitive size may limit the size and related strength or hardness of the high metal concentration regions of the coating.

[0068] After spraying, the fugitive may be removed leaving enhanced porosity. For polymer fugitive, removal may comprise a thermal burn-off. For salt fugitive, removal may comprise thermal decomposition or dissolution.

[0069] The use of "first", "second", and the like in the following claims is for differentiation within the claim only and does not necessarily indicate relative or absolute importance or temporal order. Similarly, the identification in a claim of one element as "first" (or the like) does not preclude such "first" element from identifying an element that is referred to as "second" (or the like) in another claim or in the description.

[0070] Where a measure is given in English units followed by a parenthetical containing SI or other units, the parenthetical's units are a conversion and should not imply a degree of precision not found in the English units.

[0071] One or more embodiments have been described. Nevertheless, it will be understood that various modifications may be made. For example, when applied to an existing baseline configuration, details of such baseline may influence details of particular implementations. Accordingly, other embodiments are within the scope of the following claims.

Claims

1. A method for applying an abradable coating, the method comprising:

generating a plasma (15);
introducing a matrix-forming first particulate (23) to the plasma (15) at a first location; and
introducing a second particulate (25) of an organic particulate and/or salt particulate to the plasma (15) at a second location downstream from the first location to mix with the matrix-forming first particulate (23), the second particulate (25) having a characteristic size in the range 6.0 micrometers to 45.0 micrometers; and
directing the first particulate (23) and the second particulate (25) to a target (10) to form a coating on the target (10).

2. The method of claim 1 further comprising removing the second particulate (25) from the coating so as to leave porosity.

3. The method of claim 1 or 2 wherein the second particulate (25) characteristic size is a D50 size; and optionally wherein the D50 size is 15 micrometers to 35 micrometers.

4. The method of claim 3 wherein the second particulate (25) has a D90 size of at most 45 micrometers.

5. The method of any preceding claim wherein the first particulate (23) has metallic particles of D50 particle size of 11-90 micrometers, wherein, optionally the metallic particles comprise Cu-Ni alloy or an MCrAlY.

6. The method of claim 5 wherein the first particulate (23) is an agglomerate of said metallic particles and particles of an inorganic non-metallic filler.

7. The method of any preceding claim wherein:

the second particulate (25) is introduced at a volume flow rate of 40% to 80% of a total particulate flow rate.

8. The method of any preceding claim wherein the second location is at least 0.30 inch (7.62 mm) downstream of the first location or at least 0.60 inch (15.24 mm) downstream of a nozzle outlet.

9. The method of claim 8 wherein the first location is within 2.0 diameters of a nozzle (19) downstream of the nozzle outlet.

10. The method of claim 9 wherein the second location is at least 3.0 diameters downstream of the nozzle outlet.

11. The method of any preceding claim wherein both the first particulate (23) and the second particulate (25) are injected into a core (40) of the plasma (15).

12. The method of any preceding claim wherein the coating is applied to a blade outer airseal substrate (10).

13. The method of any preceding claim wherein the coating has Vickers micro-hardness of a coating cross-section of not more than 400 measured with a 50g load in a location when 100 randomly located indents are made on the cross-section, wherein, optionally, the coating has a cohesive bond strength of 750 psi (5.17 MPa) to 2000 psi (13.8 MPa).

14. A blade outer airseal coated by the method of any preceding claim.

15. A method for applying an abradable coating, the method comprising:

generating a plasma (15);
introducing a matrix-forming first particulate (23) to the plasma (15) at a first location;
introducing a second particulate (25) of a fugitive porosity-former to the plasma (15) at a second location downstream from the first location to mix with the matrix-forming first particulate (23), the second particulate (25) fugitive-former having a characteristic size in the range 6.0 micrometers to 45.0 micrometers;
directing the first particulate (23) and the second particulate (25) to a target (10) to form a coating on the target (10); and
removing the fugitive porosity-former from the coating.

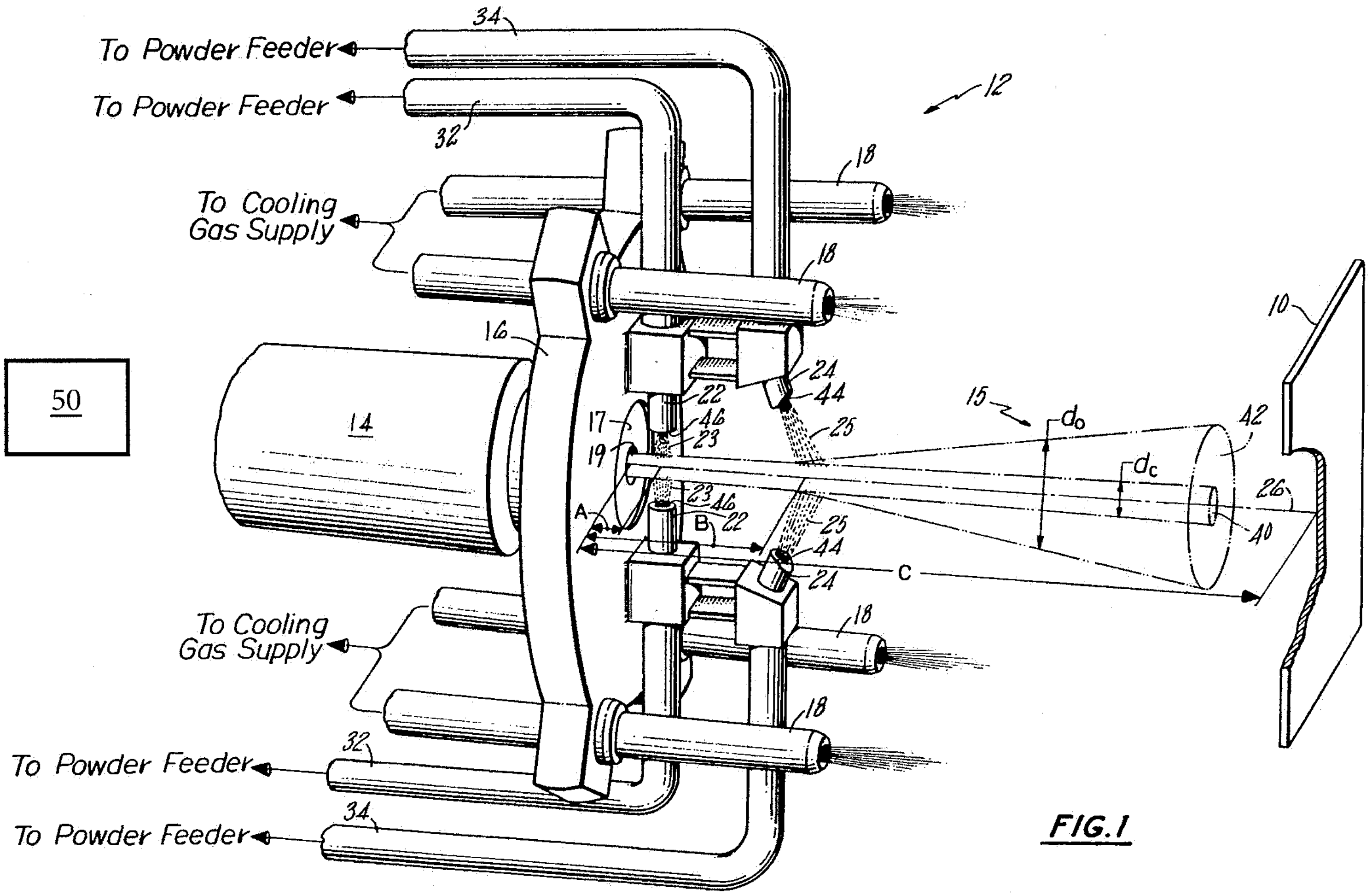
To Powder Feeder
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FIG.1

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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 3877

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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	23 November 2017	Teppo, Kirsi-Marja

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