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Guest et al.

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[54] **PROCESS FOR PLASMA FLAME SPRAY COATING IN A SUB-ATMOSPHERIC PRESSURE ENVIRONMENT**

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[52] **U.S. Cl.** ..... **427/34;** 219/121 P; 239/81

[51] **Int. Cl.** **B05b 5/06**

[58] **Field of Search** ..... 117/93.1 PF, 22, 23; 219/76, 121 P; 239/81

[56] **References Cited**

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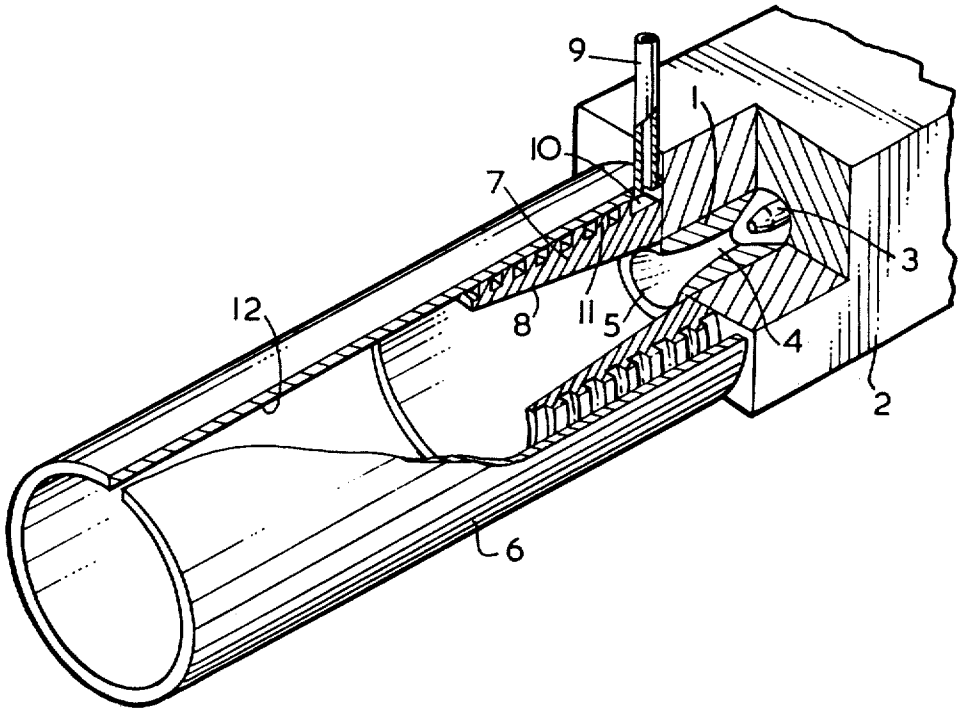
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[57] **ABSTRACT**

The invention relates to the production of plasma-sprayed coatings at low surface speeds and long stand off distances e.g. more than 7.5 cm. A zone of sub-atmospheric pressure is maintained through which the hot gas effluent and entrained coating powder produced by a plasma torch is caused to pass on its way to the substrate being coated. The sub-atmospheric zone preferably extends over the whole path of hot gas effluent and entrained coating powder. Apparatus is provided which comprises a plasma torch and a chamber preferably a tube together with means for maintaining a zone of sub-atmospheric pressure in the chamber. In the case of the tube this may be a spiral passage mounted in said tube which injects a sheath of gas moving along the inner surface of the tube in a spiral path.

2 Claims, 8 Drawing Figures



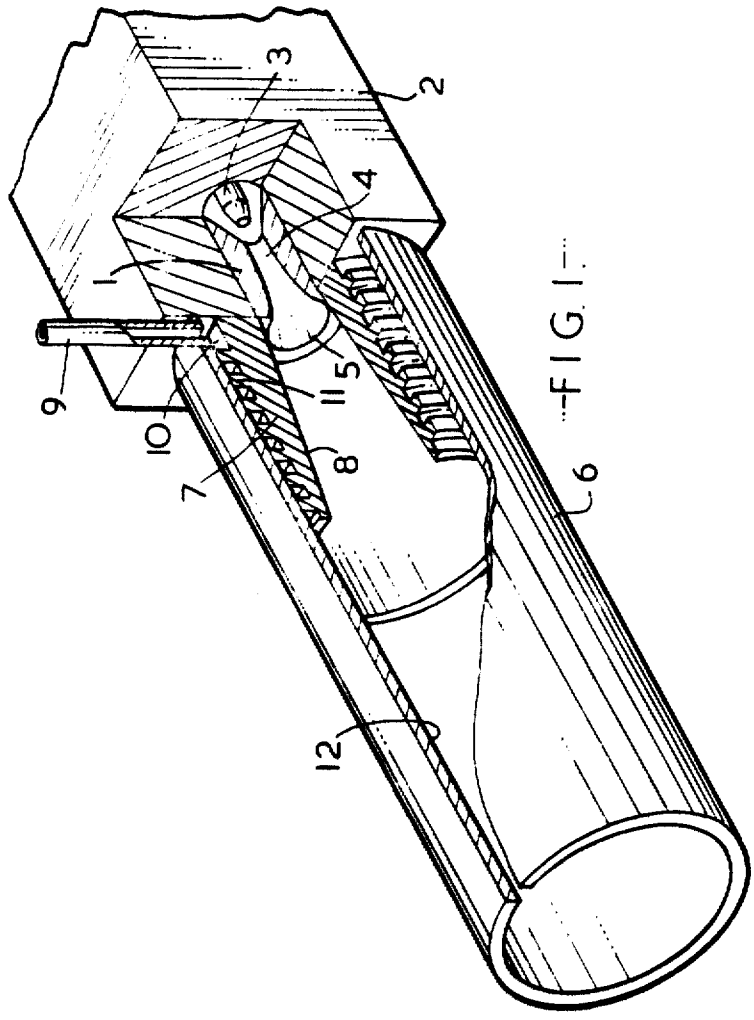
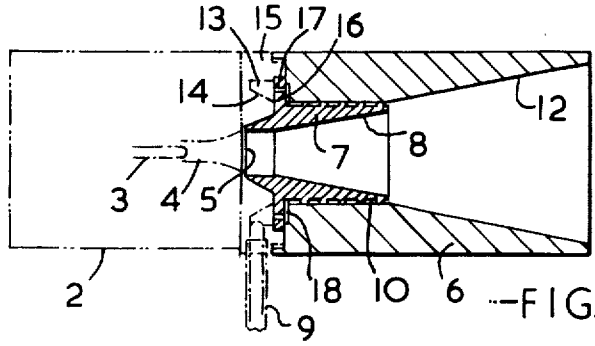
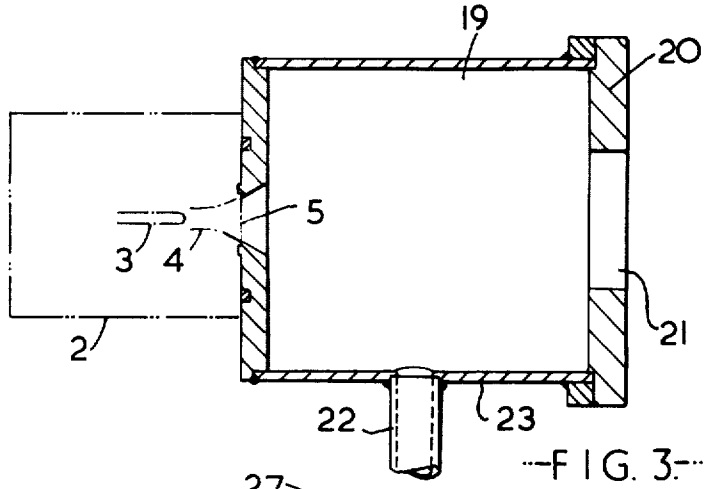


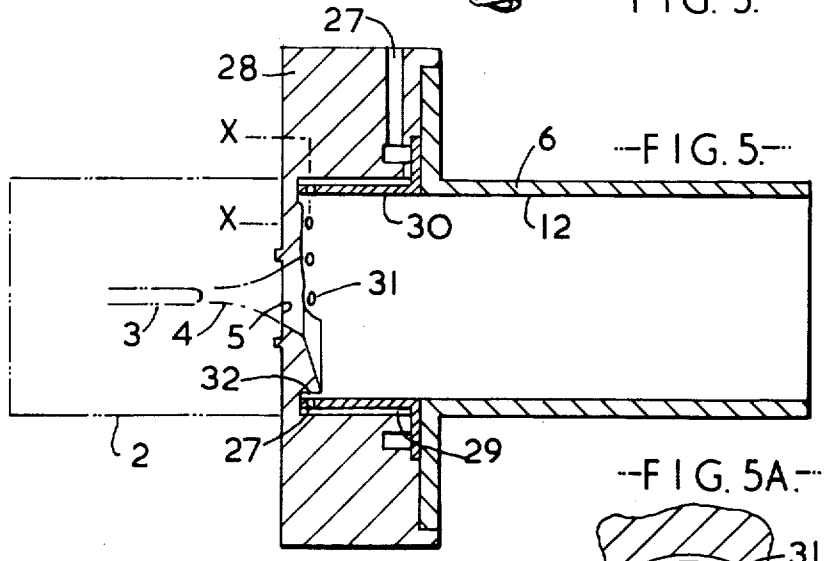
FIG. 1



--FIG. 2--

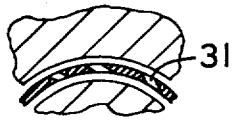


--FIG. 3--



--FIG. 5--

--FIG. 5A--



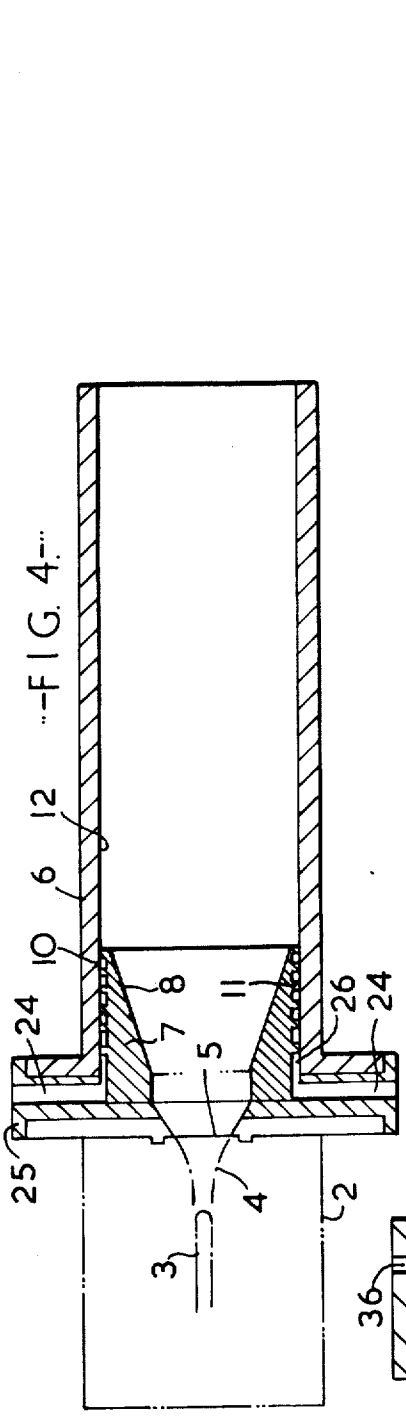


FIG. 4

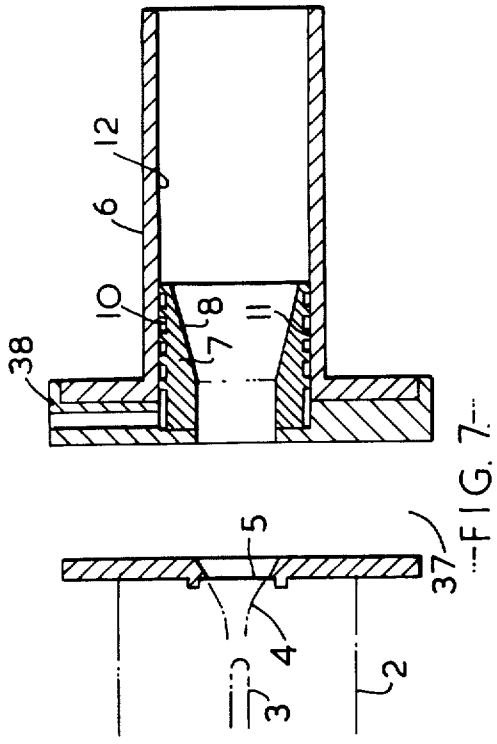


FIG. 7

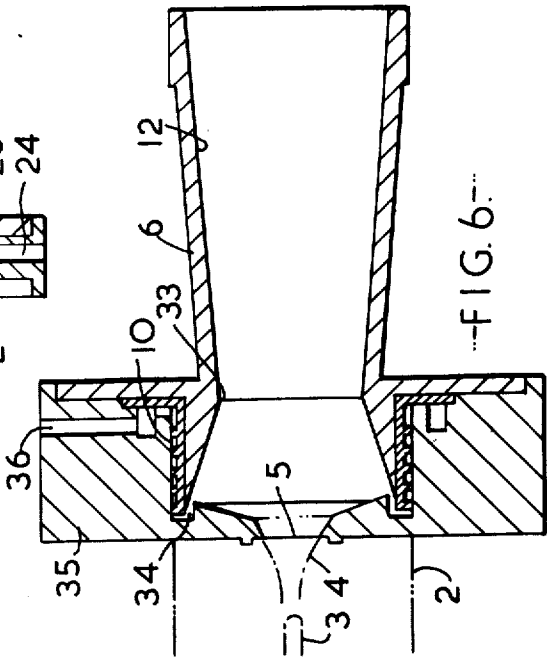


FIG. 6

PROCESS FOR PLASMA FLAME SPRAY COATING IN A SUB-ATMOSPHERIC PRESSURE ENVIRONMENT

The present invention relates to improvements in plasma arc spraying and to apparatus for same.

Plasma spraying is a coating process in which particulate coating material is injected into a plasma stream generated by a plasma torch in which stream the powder is heated and accelerated towards a workpiece to be coated. In order to achieve good properties in the resulting coating it is generally necessary to build up the coating as a series of discrete layers the thickness of each of which layers depends on the type of coating to be applied. For a given coating material however, to achieve a coating of satisfactory properties, e.g. good hardness, low porosity, no cracking and high bond strength there is a maximum limit to the thickness of each of the discrete layers.

The thickness of each discrete layer depends on the deposition flux on the coating powder and, when the workpiece is moved relative to the plasma stream as is usually the case, upon the relative speed of the workpiece to the plasma stream (called the surface speed of the workpiece).

The deposition flux depends on the feed rate of coating powder into the plasma stream and because the powder tends to spread out as it travels towards the workpiece from the point of injection, also on the distance the injected powder travels before striking the workpiece.

The lower the feed rate of coating powder, the lower the deposition flux. The longer the distance travelled by the coating powder before striking the workpiece the lower will be the deposition flux.

Plasma torches comprise a first and second electrode between which is maintained an electric arc, a gas being passed through this arc and then through an arc restricting nozzle. The gas is heated by the arc and forms a plasma which is ejected from the nozzle at high speed. The coating powder may be injected into the plasma either in the torch itself or outside the torch. Since the powder must reach the requisite temperature for coating before reaching the surface to be coated, it must remain in the plasma long enough to reach the requisite temperature, for the coating powder used.

If the coating powder is injected inside the torch into the arc itself, very rapid heating of the powder occurs so that the coating temperature is rapidly attained and the substrate to be coated can be placed only a short distance, e.g. 1.5 to 3 cm from the torch nozzle. At such close distances however very high surface speeds are necessary to achieve good coating properties, and although it has been found that such coatings exhibit by far the best properties hitherto obtainable, the economics of working in this way can prove prohibitively expensive. Also such high surface speeds sometimes involve potential safety problems which make it undesireable or impossible to work at such high speeds.

However the powder feed rate does enable some reduction in surface speed to be obtained but at the same time makes the coating time longer and therefore more costly thus negating any cost advantage in lower surface speed. Increasing the torch to substrate distance (usually called stand-off distance or simply stand-off) also enables lower surface speeds to be used but the coating produced at long stand-off have hitherto been found to have substandard hardness and a tendency to be porous.

If the powder is injected outside the torch proper the rate at which the powder is heated is lower and therefore a longer dwelling time in the plasma and consequently a longer stand-off is unavoidable. Low surface speeds are therefore usual in this type of method. The coatings produced by such methods however also suffer from substandard hardness and a tendency to be porous.

Attempts have been made to improve matters by the use of shrouds or tubes surrounding the plasma stream and by using jets of inert gas in an attempt to exclude the surrounding atmosphere and improve coating properties. Such methods have not however met with significant success at the stand-off distances which are required for low surface speed at an economic rate of powder feed.

It is an object of the present invention to provide a method of plasma arc spraying in which improved hardness and a lower tendency to porosity can be achieved at long stand-off and low surface speed.

It is a further object to provide apparatus whereby such improved results can be achieved under conditions of long stand-off and low surface speed.

According to the present invention the first object achieved by by providing in a method of producing plasma sprayed coatings in which an arc is maintained between a first and second electrode, a gas is passed into said arc to produce a hot gas effluent and said hot gas effluent passed through an arc constricting nozzle and together with a coating powder entrained therein is directed at a substrate to be coated. The length of the path from nozzle to substrate being such as to provide low deposition flux values and consequently enable low substrate surface speeds to be used, the improvement which comprises passing said hot gas effluent and entrained coating powder through a zone of sub-atmospheric pressure disposed between said nozzle and said substrate to be coated.

The distance of the substrate from the outlet of the nozzle should be for example more than 7.5 cm if low surface speeds are to be achieved at economic powder feed rates. The powder feed rate may be from 25 to 60 gms per minute depending on the density of the powder. The surface speed is preferably below 25 cm per second. The degree of vacuum in the sub-atmospheric pressure zone need not be very great, significant increases in coating quality being achieved at vacuum levels of as little as about 4 cm of mercury.

The zone of sub-atmospheric pressure should extend over a major portion of the path of the entrained coating powder and is preferably of sufficient diameter to encompass the effluent from the torch.

In one embodiment the hot gas effluent and entrained coating powder is passed through a chamber disposed between the nozzle and the substrate to be coated, the region within the chamber being maintained at a sub-atmospheric pressure by means for example of a vacuum pump. The inlet end of the chamber is preferable connected in gas tight relationship with the nozzle by suitable means. In general the surface of the substrate should be disposed close to the outlet of the chamber e.g. within about 1 cm of the outlet.

The zone of sub-atmospheric pressure preferably extends over the whole path of the effluent from nozzle to substrate. This effect may be achieved for example

by carrying out the coating process inside a vacuum tank maintained at a sub-atmospheric pressure. This embodiment does have some drawbacks in terms of e.g. access to the workpiece during coating etc, nevertheless high quality coatings can be produced at low surface speeds by this means.

A more preferred method of carrying out this invention however, is to pass the hot gas effluent and entrained coating powder through a tube in which a zone of sub-atmospheric pressure is maintained by the passage of a sheath of gas moving in a helical path along the tube between the inner surface of the tube and the hot gas effluent and entrained powder. The sheath of gas preferably passes through the tube in the same general direction as the effluent, the zone of sub-atmospheric pressure under these conditions extending a short-distance (e.g. about 1–2 cms) beyond the mouth of the tube from which the effluent flows. The area of impingement of powder on the substrate surface is preferably maintained within this extension of the sub-atmospheric zone. The inlet end of the tube is preferably connected in gas tight relationship with the nozzle when the zone of sub-atmospheric pressure may extend from the nozzle to the surface of the substrate being coated.

The tube need not be cylindrical and may for example have a taper in which the diameter of the tube increases with increasing distance from the nozzle. Other forms of tube are also possible as described hereinafter.

In the preferred form of the invention the coating powder is also injected into the arc and passed through the arc restricting nozzle.

The invention also provides apparatus for carrying out the method of the invention comprising first and second electrodes, electrical connection means for impressing on said first electrode a voltage which is capable of maintaining an arc discharge between said first and second electrodes, nozzle means for constricting said arc, means for supplying and directing gas at a controllable rate into said arc and through said nozzle to provide a hot gas effluent from said nozzle, means for entraining a coating powder at a controllable rate in said gas to provide a stream of hot gas effluent having coating powder entrained therein for direction and impingement on a substrate to be coated, enclosure means surrounding at least a portion of the path of said stream and vacuum producing means for forming and maintaining a zone of sub-atmospheric pressure in said enclosure means.

In one embodiment the chamber extends from and is connected in gas tight relationship to the nozzle and has an opening in a wall thereof remote from said nozzle and disposed to allow passage of the stream of hot gas effluent and entrained coating powder therethrough, said chamber being provided with gas out-let passage means for connection to a vacuum pump.

In a preferred embodiment the enclosure means comprises a tube and a vortex gas sheath producing means is provided for producing a sheath of gas moving in a helical path along the inner surface of the tube whereby to produce a zone of sub-atmospheric pressure in said tube. Preferably the tube is frusto-conical in shape, the narrow end of the tube being nearer to the nozzle. For best results the tube should be connected to the nozzle, preferably in gas tight relationship. Other shapes of tube may also be used.

The vortex gas sheath producing means may for example comprise gas injection means communicating with a spiral passage the outlet or outlets of which are disposed adjacent the inner surface of the tube preferably at the inlet end of the tube. Alternatively a plurality of tangentially directed gas inlet ports may be provided in the tube itself or in a separate attachment which may for example form the connection between the tube and the nozzle. The means for producing the vortex gas sheath may also be disposed in the nozzle or in the torch itself.

Any of the conventional plasma torches may be used in the method of the invention. Torches in which the coating powder is injected into the arc are preferred.

The invention will be further described by reference to the accompanying drawings in which:

FIG. 1 is a perspective view in part cut away section of one form of apparatus according to the invention.

FIG. 2. is a sectional view of an apparatus similar to FIG. 1 but having a tube the inner surface of which is of frusto-conical shape.

FIG. 3 is a sectional view of another form of apparatus according to the invention.

FIGS. 4 to 6 are sectional views of apparatus of the type of FIG. 1 with variations as to shape and manner of introducing the vortex gas sheath,

FIG. 7 is a sectional view of an apparatus similar to FIG. 1 but having a gap between the enclosure means and the nozzle.

Referring to the FIG. 1 of the drawings:

A nozzle 1 disposed within a block 2 forms the anode of a collimated arc effluent torch the other electrode of which is provided by a rod 3. The remainder of the torch is not shown. The nozzle 1 has an orifice 4 terminating in an outlet 5. Extending from the block 2 is a tube 6 attached to the block 2 by suitable means (not shown). A gas injection insert 7 disposed within the tube has a conical passage 8 formed therein and therethrough which diverges from the outlet 5 of the nozzle 1. A gas inlet conduit 9 communicates with a spiral passage 10 of rectangular cross-section formed by the abuttment of a rectangular cross-section formed by the abuttment of a rectangular screw thread 11 cut in the outer surface of insert 7 against the inner surface 12 of the tube 6. Whilst only one start on the thread 11 is shown, it may in fact have a plurality of starts. Again, whilst only one inlet conduit 9 is shown, a plurality of inlet conduits may be provided. Gas injected into conduit 9 passes into and through the spiral passage 10 whereby it acquires a spiral motion along the inner surface 12 of tube 6. This spiral motion imparted to the gas continues after it leaves the spiral passage 11 so that the gas tends by the action of centrifugal force to remain in the vicinity of the inner surface 12 of tube 6 as it passes along the tube.

Referring to FIG. 2, like numbers show like parts. The essential difference between the embodiment of FIG. 2 and that of FIG. 1 lies in the frusto-conical shape of the inner surface 12 of the tube 6 beyond the gas injection insert 7. It is believed that this configuration increases the effective diameter of the low pressure zone with increasing distance from nozzle thus reducing the tendency for spray effluent to travel in the high pressure zone near the inner surface 12 of the tube 6. In FIG. 2 the inlet conduit 9 feeds into an annular space 13 formed by a groove 14 in a distance piece 15 and an abutting flange 16 formed in gas injection insert 7. Gas

ports 17 formed in flange 16 allow gas to flow into a second annular space 18 which in turn communicates with the spiral passage 10.

Referring to FIG. 3 of the drawing a chamber 19 is attached in gas tight relationship with block 2. An end wall 20 has an opening 21 to allow passage of effluent and entrained powder out of the chamber. A conduit 22 extends from the body 23 of the chamber for connection to a vacuum pump (not shown). In operation the pressure is maintained below atmospheric by the application of suction to conduit 22 thus maintaining a zone of sub-atmospheric pressure in chamber 19. The hot gas affluent emanates from the nozzle, passes through the chamber and out of opening 21 onto a substrate (not shown) held close to opening 21.

In the embodiment of FIG. 4 the sheath gas is fed into ports 24 provided in a distance piece 25 attached on the one hand to the block 2 and on the other to tube 6. Ports 24 communicate with annular space 26 which in turn communicates with spiral passage 10.

In the embodiment of FIG. 5, a gas port 27 formed in a distance piece 28 communicates with annular space 29 formed between distance piece 28 and a flanged annular insert 30 in which are formed a plurality of tangentially disposed gas ports 31 which extend from annular space 29 to an annular channel 32. Sheath gas is supplied to port 27 from which it flows via annular space 29, through gas ports 31 into the annular channel 32 and thence along the inner surface of insert 30 and thence along inner surface 12 of tube 6. The disposition of ports 31 imparts a helical motion to the sheath gas. FIG. 5A shows a section on the line X—X of FIG. 5 and shows the angular orientation of ports 31.

In the embodiment of FIG. 6 the tube 6 has a constriction formed in the interior thereof, the inner surface 12 tapering from its mould inwardly to a minimum diameter at 33 and then outwardly again to an annular channel 34 formed in a distance piece 35. A spiral passage 10 is formed between annular channel 34 and gas inlet port 36. Sheath gas fed into gas inlet port 36 is given a spiral motion by spiral passage 10 an passes via channel 34 along the inner surface 12 of tube 6.

In the embodiment of FIG. 7 a gap 37 is left between the outlet 5 and the distance piece 38 the two sections of the apparatus being held rigidly in this position by means not shown. The means for forming the vortex sheath is similar to that in FIGS. 1 and 4.

The method of the invention will be further illustrated by reference to the following Examples:

EXAMPLE I

An arc effluent coating torch of the type described and claimed in U.K. Pat. No. 869,791 was modified by being provided with an extension as generally illustrated in the accompanying drawings. The tube had a length of 12.7 cm and an internal diameter of 3.5 cm. The gas injection means had a four start thread of two teeth per inch of rectangular cross-section the width of cut being 2.38 mm and the depth of cut 1.19 mm, the injection means having an overall length of 2.54 cm.

This modified torch was used to coat a previously grit-blasted workpiece, the workpiece being placed 1.3 cm from the mouth of the tube for a period sufficient to build up an adequate coating (about 3 seconds). The workpiece and torch remained stationary during the coating. The coating material was a Stellite 31 (a cobalt based alloy composition 20% Cr 10% Ni 7.5% W and balance Co) in the form of a-325 mesh powder. A torch gas flow of 162 cubic feet per hour CFH a powder carrier gas flow of 138 CFH, and an envelope gas flow of 775 CFH, all of Argon were used, the powder feed rate being 37 gm. per minute. The coating obtained had the folliowing properties:

Oxide content 0.2%
Porosity 0.2%
Cross-section Micro Hardness 292VPN
Bond Strength greater than 7,960 p.s.i.

No cracking or separation of the coating was observed.

If the unmodified torch had ben used under the above conditions even 3.8 cm from the workpiece a relative speed of 25,400 cm per minute as between workpiece and torch would have been necessary to enable a similar coating to be applied.

EXAMPLE II

In this example two modified torches were used (a) similar to that described in Example I but having an inner tube diameter of 2.54 cm and an unthreaded gas injection means providing an annular space 1.19 mm thick between injection means and the tube, and (b) similar to that of Example I but having a 2.54 cm inner diameter tube and a gas injection means threaded in the manner of Example I. The modified torches were operated with a torch gas flow of 162 CFH and powder carrier gas flow of 162 CFH both of Argon and a powder feed rate of 25 gms per minute of chromium oxide. Three tests were carried out as follows, the workpiece being stationary realtive to the torch in each case and 2.54 cm from the end of the tube:

i. No gas envelope using modified torch A. The coating obtained had the following properties:
Porosity 5 percent
Cross-sectional Micro Hardness 1204 VPN

ii. A gas envelope of Argon was injected through the annular space of torch A at a flow rate of 775 CFH to flow in a direction parallel to the longitudiinal axis of the tube. The coating had the following properties:
Porosity 4 percent
Cross-sectional Micro Hardness 966 VPN

iii. Using Torch B and two different envelope gases the following results were achieved:

ENVELOPE GAS FLOW	GAS	COATING POROSITY	COATING CROSS-SECTIONAL MICRO-HARDNESS
775 CFH	Argon	2.5%	1300 VPN
675 CFH	Nitrogen	3.0%	1261 VPN

The above results should be compared with those obtained in the following comparative Example:

COMPARATIVE EXAMPLE

i. Using an unmodified torch and the same torch gas feed, powder carrier gas feed and powder feed rate as in Example II, a stand-off of 1.9 cm and a relative speed of workpiece to torch of 30,480 cm per minute coatings were obtained having porosities less than 3 percent

usually 1 to 2 percent and cross-sectional micro hardness in the range 1,150 to 1,400 VPN.

ii. Using a stand-off of 5 inches and the workpiece stationary relative to the torch of the porosity rose to 5 percent and the cross-sectional microhardness dropped to 890 VPN.

In the following examples MSI is the volume of coating of 1 mil thickness by 1 sq. inch area. 1,000 MSI = 1 cubic inch of coating. Mils/sec is 0.001 inch (or 0.0254 mm) per sec of coating. The porosity figures quoted were obtained by visual technique using comparison standards, where numbers 10 or 20 are quoted within brackets these relate to the average size in microns of the holes as assessed by visual technique. Hardness figures were obtained according to ASTM-E-92. When the presence of oxide is quoted the amount is as assessed by visual techniques.

EXAMPLE IV

An apparatus of the type of FIG. **2** of overall tube length 3 3/**16** inch (8.1 cm) and tapering from an internal diameter of 1 inch (2.54 cm) at the point of injection of sheath gas at an angle of 22° over an axial length of 2 inches (5.08 cm) was used under the following conditions and produced the results set out in Table II.

Torch Conditions	
Powder composition:	Chrome sesquioxide
Powder feedrate:	30 grams per minute
Torch type:	Model No. 1101A
Arc power:	9.0 kw
Total torch gas flow:	300 cfh
Gas composition:	Argon
Stand off	4.5 inches (11.43 cm)
Surface speed	100 inches (254 cm) per minute

Table II

Method of Obtaining Vacuum	Vacuum (in. Hg)	Coating Data		
		Hardness VPN	Porosity %	Deposition Rate (mils/sec)
Torch alone	0	963	4.5	5.3
800 cfh argon sheath gas	1.6	1183	3.5	9.5
1200 cfh argon sheath gas	2.7	1155	3.0	9.7
2000 cfh argon sheath gas	4.6	1103	2.5	11.2

EXAMPLE III

An apparatus similar to FIG. **2** but having a cylindrical tube of 1 inch (2.54 cm) diameter and overall length of 3 11/**16** inches (9.37 cm) was employed to produce coatings under the following conditions and produced the results shown in Table I.

Torch Conditions	
Powder composition:	Chrome sesquioxide
Powder feedrate:	30 grams per minute
Torch type:	Model No. 1101A
Arc power:	9.0 kw
Total torch gas flow	300 cfh
Gas composition:	Argon
Stand off	4.5 inches (11.43 cm)
Surface speed	100 inches (254 cm) per minute

Table I

Method of Obtaining Vacuum	Vacuum (in. Hg)	Coating Data		
		Hardness VPN	Porosity %	Deposition Rate (mils/sec)
Torch alone	0	963	4.5	4.8
800 cfh argon sheath gas	2.4	1041	3.5	10.0
1600 cfh argon sheath gas	4.7	1092	3.5	7.5
2000 cfh argon sheath gas	6.2	1043	5.0	7.5

EXAMPLE V

An apparatus of the type shown in FIG. **3** in which the chamber has an overall length of 3 ⅞ inches (9.84 cm) and the outlet is 1 ⅜ inches (3.48 cm) in diameter was used to produce coatings under the following conditions and gave the results set out in Table III.

Torch Conditions	
Powder composition:	Chrome sesquioxide
Powder feedrate:	30 grams per minute
Torch type:	Model No. 1101A
Arc power:	9.0 kw
Total torch gas flow:	300 cfh
Gas composition:	Argon
Stand off	4¼ inches (10.8 cm)
Surface speed	zero

Table III

Method of Obtaining Vacuum	Vacuum (in Hg)	Coating Data		
		Hardness VPN	Porosity %	Deposition Rate (mils/sec)
Torch alone	0	963	4.5	4.8
22 psig on steam ejector	1.5			8.6
34 psig on steam ejector	3.0			8.2
51 psig on steam ejector	6.0			8.9
65 psig on steam ejector	9.0	1353	2.5	10.1
84 psig on steam ejector	14.0	1344	2.5	10.7

EXAMPLE VI

A standard torch was used to produce coatings in a substrate, the torch and substrate being disposed wholly within a vacuum tank connected to a steam ejector. The conditions of coating were as follows and produced the results set forth in Table IV.

Torch Conditions	
Powder composition:	Chrome sesquioxide
Powder feedrate:	30 grams per minute
Torch type:	Model No. 1101A
Arc power:	9.0 kw
Total torch gas flow:	300 cfh.
Gas composition:	Argon
Stand off	4.5 inches (11.4 cm)
Surface speed	100 inches (254 cm) per minute

Table IV

Method of Obtaining Vaccum	Vacuum (in Hg)	Coating Data		
		Hardness VPN	Porosity %	Deposition Rate (mils/sec)
Coated into atmosphere	0	963	4.5	2.6
34 psig on steam ejector	3.0	1244	2.0	4.5
51 psig on steam ejector	6.0	1306	1.5	4.0
65 psig on steam ejector	9.0	1257	1.5	5.0
77 psig on steam ejector	12.0	1268	0.75	4.5

EXAMPLE VII

Using the methods and apparatus described in Examples IV, V and VI with three different coating materials the following results were achieved as set out in Table V.

TABLE V. Material Comparison

Material and Conditions		VACUUM TANK Coating Data			
		Vacuum (in. Hg)	Hardness VPN	Porosity %	Deposition Rate (mils/sec)
Chrome Sesquioxide		0	963	4.5	4.8
Powder feedrate:	30 gm/min	3.0	1244	2.0	8.2[1]
Torch type:	1101A				
Arc power:	9.0 kw				
Total torch gas flow:	300 cfh	6.0	1306	1.5	8.9[1]
Gas composition:	argon				
Tungsten Carbide-Cobalt		0	725	3.0 at 20μ	5.7
		2.7			9.6[2]
Powder Feedrate:	55 gm/min	3.0	727	2.5 at 10μ	
Torch type:	1101A				
Arc power:	9.0 kw	4.6			8.6[2]
Total torch gas flow:	300 cfh	6.0	738	2.5 at 10μ	
Gas composition:	argon				
Aluminum Bronze		0	104	0.5	4.5
Powder feedrate:	40 gm/min	3.0	206	0.5	5.3
Torch type:	1101E				
Arc power:	9.0 kw				
Total torch gas flow:	300 cfh	6.0	200	0.75	5.3
Gas composition:	argon	12.0			8.5

1. Apparatus of FIG. 3.
2. Apparatus of FIG. 2.

EXAMPLE VIII

Using the apparatus of FIG. 4 with a tube of overall length 5 inches (12.7 cm) of cylindrical shape and internal diameter 1 ⅜ inches (3.49 cm) the spiral passage is a 4 start thread 2 teeth per inch (254 cm) and a sheath gas feed rate of 775 cubic feet (21,954 litres) per hour conditions and coating powders set forth below the following results were obtained.

Table VI

Coating Type	Powder feed rate (gm/minute)	Surface speed per sec.	Properties of coating			
			Hardness VPN	Bond Strength lb/m²	Porosity %	Oxide %
LA6	36	5 inches (12.7 cm)	927	9,000+	4	—
LN-2B	40	"	147	8,500+	0.1	Less than 0.1
52-F	37	"	598	7,000+	1 to 1.5	—
X-40	35	"	405	8,630+	0.5	1
LT-1	28	1 inch (2.54 cm)	265	8,800+	0.5	Less than 0.25
LS-31	37	5 inches (12.7 cm)	254	8,600+	0.25	3

The coating types in Table VI are as follows:

LA-6	Aluminium Oxide (Al_2O_3)
LN-2B	Pure Nickel
52-F	81.41% Tungsten Carbide 17.61% Cobalt
X-40	56% Cobalt 25% Chromium 10% Nickel 7% Tungsten 0.3% Carbon
LT-1	Pure Tantalum
LS-31	20% Chromium 10% Nickel remainder Cobalt 7.5% Tungsten

EXAMPLE IX

Using the apparatus of FIG. 5 with a cylindrical tube of overall length 3½ inches (8.9 cm) internal diameter 1 ⅜ inches (3.49 cm), the spiral passage being a 4 start thread 2 teeth per inch, chromium oxide (Cr_2O_3) was used at a powder feed rate of 45 gm per minute and a substrate surface speed of 5 inches (12.7 cm) per second the sheath gas feed rate being 775 cubic feet (21,945 litres) of argon per hour, a coating of the following properties was obtained:

Hardness VPN	1006
Bond strength lb/in²	8000(562.4 Kg/cm²)
Porosity	4% (10)

EXAMPLE X

Using the apparatus of FIG. 6 with a tube of overall length 3½ inches (869 cm) minimum diameter 1 inch (2.54cm) maximum diameter 1⅜ inches (3.49 cm) and outward taper 8° with a spiral passage formed by a 4 start 2 teeth per inch thread was used with a sheath gas feed rate of 775 cubic feet (21,945 litres) per hour of argon and a powder feed rate of 26 gm per minute of chromium oxide (Cr_2O_3) and a surface speed of 5 inches (12.7 cm) per second and produced the following properties in a coating:

Hardness VPN	1204
Bond strength lb/in²	11000+ (774 + Kg per cm²)
Porosity	4% (10)

EXAMPLE XI

The apparatus of FIG. 7 was used with a tube length of 3 inches (7.62 cm) an internal diameter of 1 inch (2.54 cm), the gap between nozzle and tube being ¾ – 1 inch (1.9–2.54 cm), the spiral passage a 4 start 2 teeth per inch (2.54 cm) thread and a sheath gas feed rate of 775 cubic feet (21,945 litres) per hour of argon and a powder feed rate of 26 gm per minute of chromium oxide (Cr_2O_3) at a surface speed of 5 inches (12.7 cm) per second and produced a coating having the following properties.

Hardness VPN	1261
Porosity	3% (10)

We claim:

1. A method for producing plasma sprayed coatings comprising

maintaining an arc between a first and second electrode;

passing a gas into said arc to produce a hot gas effluent;

introducing a coating powder into said hot gas effluent;

passing said coating powder entrained hot gas effluent through an arc constricting nozzle;

surrounding said coating powder entrained hot gas effluent by a vortical flow of gas moving in the same direction as said hot gas effluent to provide a zone of sub-atmospheric pressure from said nozzle substantially to a substrate to be coated;

maintaining said coating powder entrained hot gas effluent within said zone of sub-atmospheric pressure until it strikes said substrate.

2. A method according to claim 1 wherein said vortical flow of gas is established in a nozzle connected in gas tight relationship with said arc constricting nozzle.

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