



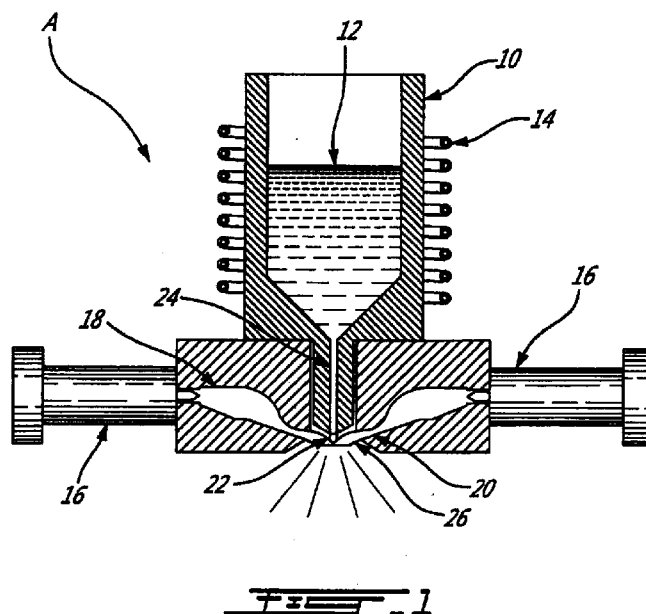
- (51) International Patent Classification:
B22F 9/14 (2006.01) B22F 9/18 (2006.01)
- (21) International Application Number:
PCT/CA2019/000034
- (22) International Filing Date:
18 March 2019 (18.03.2019)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
62/644,459 17 March 2018 (17.03.2018) US
- (71) Applicant: **PYROGENESIS CANADA INC.** [CA/CA];
1744 Rue William, Suite 200, Montréal, Québec H3J 1R4 (CA).
- (72) Inventors: **ALLARD, Bernad**; 578 rue Crémazie, Beloeil, Québec J4G 4B8 (CA). **CARABIN, Pierre**; 4353 avenue

Girouard, Montréal, Québec H4A 3E5 (CA). **DORVAL DION , Christopher Alex**; 3125 rue Allard, Montréal, Québec H4E 2M8 (CA). **PROULX, François**; 5481 Queen Mary rd., Montréal, Québec H3X 1V4 (CA).

(74) Agent: **BENOIT & COTE INC.**; 300-560 Crémazie Blvd. East, Montréal, Québec H2P 1E8 (CA).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(54) Title: METHOD AND APPARATUS FOR THE PRODUCTION OF HIGH PURITY SPHERICAL METALLIC POWDERS FROM A MOLTEN FEEDSTOCK



(57) Abstract: An apparatus for producing metallic powders from molten feedstock includes a heating source for melting a solid feedstock into a molten feed, and a crucible for containing the molten feed. A liquid feed tube is also provided to feed the molten feed as a molten stream. A plasma source delivers a plasma stream, with the plasma stream being adapted to be accelerated to a supersonic velocity and being adapted : to then impact the molten stream for producing metallic powders. The feed tube extends from the crucible to a location where a supersonic plasma plume atomizes the molten stream. The plasma source includes at least two plasma torches provided with at least one supersonic nozzle aimed towards the molten stream. The multiple plasma torches are disposed symmetrically about the location where the supersonic plasma plumes atomize the molten stream, such as in a ring-shaped configuration.



(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

TITLE

METHOD AND APPARATUS FOR THE PRODUCTION OF HIGH PURITY SPHERICAL METALLIC POWDERS FROM A MOLTEN FEEDSTOCK

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This Application claims priority on U.S. Provisional Application No. 62/644,459, now pending, filed on Mar 17, 2018, which is herein incorporated by reference.

FIELD

[0002] The present subject matter relates to advanced materials and, more particularly, to the production of metal powders for diverse applications, such as additive manufacturing for the aerospace and medical industries.

BACKGROUND

[0003] Water atomization uses water as an atomizing medium to atomize a molten stream of metal into very fine particles. Since water is an incompressible fluid, a high pressure jet provides both the density and the velocity required to produce fine powders at large production rates. However, water atomization has several limitations in terms of applications due to contamination from water, and the highly irregular and angular shape of the powder so produced.

[0004] As to gas atomization, it can produce metallic powders of high purity by hitting a molten stream with a high pressure inert gas jet. However, this method generally either results in a very low yield as to powders of finer size, or has a relatively low production rate. To achieve a good compromise between both these aspects, very high pressures are required to create a cold supersonic jet. Atomizing with cold gas has the down side of freezing the molten particles too rapidly, which causes gas entrapment within the particles, whereby such powders

are less suitable for 3D printing applications, as it affects directly the density of the printed part. Also, due to a fast quenching rate, the shape of the particles is often spheroidal but not spherical. Satellite is also often a problem with this technology, as the large amount of gas used causes intense turbulence powder that forces the recirculation of the finer particles in the cooling chamber.

[0005] Turning to plasma atomization, it typically uses a wire instead of a molten stream as a feedstock, and uses a source of plasma (a.k.a. plasma torch) as the atomizing agent to break up the particles. Using a wire provides the stability required to ensure that the narrow plasma jets are aiming properly at wire, since the wire has to be melted and atomized in a single step. This technology currently produces the finest, most spherical and densest powder on the market. In other words, the yield of powder produced in the 0-106 micron range is very high, sphericity is near perfect, and gas entrapment is minimized. However, this technology has two main disadvantages. First, dependence on wires as feedstock is significantly limiting, as some materials are too brittle to be made in the form of wire. Using a wire also implies adding cost to the feedstock material as ingots must be melted again so as to be extruded for producing the wire in question. The second major disadvantage is the much lower production rate in comparison to water atomization and to gas atomization. Reported production rates from plasma atomization companies are up to 13 kg/h. An expert in the field would recognize that a more realistic range for optimal particle size distribution would be much lower. For example, U.S. Patent No. 5,707,419, which is entitled "Method of Production of Metal and Ceramic Powders by Plasma Atomization" and issued in the names of Tsantrizos et al. on January 13, 1998, reports a feed rate of 14.7 g/min or 0.882 kg/h for titanium, while U.S. Patent Application Publication No. 2017/0326649-A1, which is entitled "Process and Apparatus for Producing Powder Particles by Atomization of a Feed Material in the Form of an Elongated Member" and which was published on November 16, 2017 with Boulos et al. as inventors, discloses a reported feed rate of 1.7 kg/h for stainless steel.

[0006] Therefore, it would be desirable to provide an apparatus and a method for producing metallic powders from sources other than wires, and at a significant production rate.

SUMMARY

[0007] It would thus be desirable to provide a novel apparatus and method for producing metallic powders from molten feedstock.

[0008] The embodiments described herein provide in one aspect an apparatus for producing metallic powders from molten feedstock, comprising:

[0009] a heating source for melting a solid feedstock into a molten feed;

[00010] a crucible for containing the molten feed;

[00011] a delivery system to feed the molten feed as a molten stream;
and

[00012] a plasma source adapted to deliver a plasma stream;

[00013] the plasma stream being adapted to be accelerated to a supersonic velocity and being then adapted to impact the molten stream for producing metallic powders.

[00014] Also, the embodiments described herein provide in another aspect a process for producing metallic powders from molten feedstock, comprising:

[00015] providing a molten feed;

[00016] delivering the molten feed as a molten stream;

[00017] providing a plasma stream;

[00018] accelerating the plasma stream to a supersonic velocity; and

[00019] impacting the molten stream with a supersonic plasma plume

for producing metallic powders.

BRIEF DESCRIPTION OF THE DRAWINGS

[00020] For a better understanding of the embodiments described herein and to show more clearly how they may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, which show at least one exemplary embodiment, and in which:

[00021] Fig. 1 is a schematic vertical cross-sectional view of an apparatus for producing metallic powders from molten feedstock in accordance with an exemplary embodiment;

[00022] Fig. 2A is a schematic vertical cross-sectional view of another apparatus for producing metallic powders from molten feedstock in accordance with an exemplary embodiment;

[00023] Fig. 2B is a schematic bottom plan view of the apparatus of Fig. 2A;

[00024] Fig. 3A is a schematic elevational view of an apparatus for producing metallic powders from solid or liquid feedstock in accordance with a further exemplary embodiment; and

[00025] Fig. 3B is a schematic vertical cross-sectional view of the apparatus of Fig. 3A.

DESCRIPTION OF VARIOUS EMBODIMENTS

[00026] The present approach herein disclosed provides methods and apparatuses for producing metallic powders from sources other than wires, such as liquid or solid feedstock.

[00027] It is known that wires should be used in order to have a viable plasma-based atomization process. In the present subject matter, a supersonic plasma jet is used to atomize a molten stream, and there follows various embodiments related thereto.

[00028] A plasma atomization process that uses a wire ensures that the metal is in proper contact with the plasma jet to maximize heat and momentum transfer, such that the wire can be melted and atomized in a single step. However, there seems to be no physical reasons why the power required to melt continuously the metal should necessarily be provided by the plasma source. In gas and water atomizations, the melting and atomization are two distinct steps. This configuration allows greater production rates, as a result that the melting rate is not limited by the heat transfer and residence time between a supersonic jet and the feedstock.

[00029] The present subject matter provides a way to atomize a liquid feed using plasma jets, as in gas and water atomizations.

[00030] More particularly, a source of plasma, such as one or multiple plasma torches, is provided to deliver a plasma stream that can be accelerated to supersonic velocity prior to hitting the molten stream with high momentum.

[00031] The application of this concept is more complicated in practice than the previous statement may suggest, as supersonic plasma jets can hardly be contained since they create a very harsh environment for materials to survive.

[00032] For example, the melting point of Titanium alloy (Ti-6Al-4V) is around 1660 °C. In order to provide a proper period of time for the liquid particle to reach a spherical shape, there is delivered a gas jet that is above the melting point of the material to be atomized. For Ti-6Al-4V, a jet temperature of around 1900 °C is preferred. On the basis that supersonic speeds convert thermal heat and pressure into Mach velocities, it is to be expected that the temperature drops significantly between before (upstream of) and after (downstream of) the throat of the supersonic nozzle. Accordingly, to get a Mach jet at 1900 °C at the apex (point of convergence between the plasma jet(s) and the molten stream to be atomized), a temperature above 2500 °C might be required at the inlet of the supersonic nozzle. Considering the heat losses of the high pressure and temperature chamber prior to the nozzle, it can be comfortably stated that the plasma source should have a plume temperature of above 3000 °C. Commercial high enthalpy

torches can provide this kind of temperature in a reliable way with commercially available spare parts.

[00033] Dealing with supersonic plasma jets in a confined area is always delicate. Due to the nature of these jets, there results a very harsh environment for materials to sustain, due to very high temperatures, thermal shocks and mechanical erosion. For this reason, proper materials should be chosen for the design of the plasma path from the torch to the apex. At temperatures above 3000°C, 1 to 2 Mach speed can represent 1500 m/s. Example of materials that can be used are graphite for the chamber, and for the nozzle hard refractory elements that have very high melting point as well as their carbides, such as tungsten, tungsten carbide, titanium carbide, hafnium, hafnium carbide, Niobium, Niobium carbide, tantalum, tantalum carbide, molybdenum, molybdenum carbide, etc. It is also preferable to operate under an inert atmosphere, not only for the quality of the powder produced (to reduce its potential for oxidation), but also to help the survival of the high temperature materials mentioned hereinabove.

[00034] The source of plasma stream can come from a single source or a combination of multiple sources, as detailed hereinafter.

[00035] With reference to Fig. 1 and to Figs. 2A and 2B, embodiments are shown wherein a feedstock is molten and is fed centrally through a ring of plasma torches, either connected to a gas channel leading to a single annular supersonic nozzle (Fig. 1) or to their individual nozzles (Figs. 2A and 2B) focused on an apex. The melt can be achieved either through conductive heating from the plasma plume or by any other means of melting the metal. The melt can be directed through the feeding tube by gravity, gas pressure or a piston or any combination thereof.

[00036] More particularly, Fig. 1 illustrates an apparatus A for producing metallic powders from molten feedstock, which comprises a melt crucible 10 adapted to contain a melt 12 and heated by induction 14 or otherwise. Multiple commercial plasma torches 16 are connected to a donut-shaped plenum chamber 18. The plasma torch outlets are connected tangentially to force a vortex inside

the donut-shaped chamber 18, thereby allowing for a proper plasma gas mixing and uniform mixture. An outlet 20 of the donut-shaped chamber 18 can either be in the shape of a single annular supersonic nozzle aimed towards a molten feedstock stream 22, or it can include multiple supersonic holes (nozzles) also aimed towards the molten stream 22 at the center. A feed tube 24 for the liquid feedstock 22 is provided between the melt crucible 10 and a location where a supersonic plasma plume 26 is adapted to atomize the molten stream.

[00037] In Figs. 2A and 2B, another apparatus A' for producing metallic powders from molten feedstock is shown, wherein a number of small diameter plasma torches 116 are provided with a cylindrical supersonic nozzle being installed on each torch 116. The plasma torches 116 are arranged in a ring-shaped configuration, as best seen in Fig. 2B, and each plasma torch 116 is aimed directly at the falling molten stream (liquid feedstock) 122, the torches being annularly disposed with respect to the molten stream 122. As above, the apparatus A' includes a melt crucible 110 adapted to contain a melt 112 and to be heated by induction 114 or other suitable means. Supersonic nozzles are provided at 120 and are aimed at the molten feedstock stream 122, with supersonic plasma plumes being shown at 126. A feed tube 124 for the liquid feedstock is provided between the melt crucible 110 and a location where the supersonic plasma plumes 126 are adapted to atomize the molten stream.

[00038] Now turning to Figs. 3A and 3B, there is illustrated thereat a further apparatus A'' for producing metallic powders from molten feedstock, but also from solid feedstock. In the method associated with the apparatus A'', a solid or liquid feedstock 212 is fed via a crucible/feed guide 210 through an annular plasma torch. The apparatus A'' also includes a pusher 202 (for the solid feedstock), but could be combined with a liquid feed instead. The annular torch comprises a set of electrodes 200 put in series which can heat an inert gas to a plasma state and accelerate it to impact a rod of feedstock 212 so as to atomize the feedstock 212. In Fig. 3B, an electric arc is shown at 204 and a plasma plume is denoted by 226. The feedstock 212 can be preheated with induction 214 or resistively.

[00039] For each of the above-described apparatuses A, A' and A", in the horizontal axis, it is suggested for the supersonic jets to be aimed with an angle that pushes downward the molten stream (jet).

[00040] The molten stream can be obtained from rods or ingot as well as from other sources. The technique(s) used to melt the solid feedstock into a molten stream and to bring the same to the apex zone is irrelevant as long as the appropriate velocity, pressure and temperature are provided by such technique(s).

[00041] In the present exemplary embodiments, the plasma source is an arc plasma torch because of its common availability. However, many other ways for achieving the thermal plasma state could be used. For example, inductively-coupled, microwave, and capacitive plasma sources could be used as well.

[00042] Another interesting aspect of the present subject matter resides in that, since the gas and/or plasma has such a high temperature at the inlet of the supersonic nozzle, much lower pressures are required to reach Mach speed. Such lower pressures significantly reduce the cost of the installation and the thickness required for the parts. For the exemplary embodiments mentioned hereinabove, an inlet of 10 atm is sufficient to feed the entire setup, while fine particle gas atomization often uses pressures in the order of magnitude of the 40-450 atm.

[00043] While the above description provides examples of the embodiments, it will be appreciated that some features and/or functions of the described embodiments are susceptible to modification without departing from the spirit and principles of operation of the described embodiments. Accordingly, what has been described above has been intended to be illustrative of the embodiments and non-limiting, and it will be understood by persons skilled in the art that other variants and modifications may be made without departing from the scope of the embodiments as defined in the claims appended hereto.

REFERENCES

- [1] Peter G. Tsantrizos, François Allaire and Majid Entezarian, "Method of Production of Metal and Ceramic Powders by Plasma Atomization", U.S. Patent No. 5,707,419, January 13, 1998.
- [2] Christopher Alex Dorval Dion, William Kreklewetz and Pierre Carabin, "Plasma Apparatus for the Production of High Quality Spherical Powders at High Capacity", PCT Publication No. WO 2016/191854 A1, December 8, 2016.
- [3] Michel Drouet, "Methods and Apparatuses for Preparing Spheroidal Powders", PCT Publication No. WO 2011/054113 A1, May 12, 2011.
- [4] Maher I. Boulos, Jerzy W. Jurewicz and Alexandre Auger, "Process and Apparatus for Producing Powder Particles by Atomization of a Feed Material in the Form of an Elongated Member", U.S. Patent Application Publication No. 2017/0326649 A1, November 16, 2017.
- [5] "Titanium MIM Moves into the Mainstream with Plasma Atomised Powders from AP&C", Powder Injection Moulding International, Vol. 11, No. 2, June 2017.

CLAIMS

1. An apparatus for producing metallic powders from molten feedstock, comprising:
 - a heating source for melting a solid feedstock into a molten feed;
 - a crucible for containing the molten feed;
 - a delivery system to feed the molten feed as a molten stream; and
 - a plasma source adapted to deliver a plasma stream;the plasma stream being adapted to be accelerated to a supersonic velocity and being then adapted to impact the molten stream for producing metallic powders.
2. The apparatus as defined in Claim 1, wherein the plasma stream is delivered via at least one plasma source.
3. The apparatus as defined in any one of Claims 1 and 2, wherein the delivery system includes a liquid feed tube extending from the crucible such as to deliver the molten feed downstream to a location where a supersonic plasma plume is adapted to atomize the molten stream.
4. The apparatus as defined in any one of Claims 1 to 3, wherein the plasma source includes at least two plasma torches connected to a plenum chamber.
5. The apparatus as defined in Claim 4, wherein the plenum chamber is donut-shaped.
6. The apparatus as defined in any one of Claims 4 to 5, wherein outlets of the plasma torches are connected tangentially to force a vortex inside the plenum chamber.

7. The apparatus as defined in any one of Claims 4 to 6, wherein an outlet of the plenum chamber includes a single annular supersonic nozzle aimed towards the molten stream.
8. The apparatus as defined in any one of Claims 4 to 6, wherein an outlet of the plenum chamber includes multiple supersonic holes aimed towards the molten stream.
9. The apparatus as defined in Claim 8, wherein the supersonic holes include nozzles.
10. The apparatus as defined in any one of Claims 8 to 9, wherein the supersonic holes are centrally aimed at the molten stream.
11. The apparatus as defined in any one of Claims 4 to 10, wherein the molten feed in the crucible is adapted to be heated by induction, which is typically disposed around the crucible.
12. The apparatus as defined in any one of Claims 1 to 3, wherein the plasma source includes at least two plasma torches each provided with a cylindrical supersonic nozzle.
13. The apparatus as defined in Claim 12, wherein there are provided at least four plasma torches, disposed symmetrically about the location where supersonic plasma plumes atomize the molten stream.
14. The apparatus as defined in Claim 13, wherein there are provided at least six plasma torches, disposed symmetrically about the location where the supersonic plasma plumes atomize the molten stream.

15. The apparatus as defined in any one of Claims 12 to 14, wherein the plasma torches are arranged in a ring-shaped configuration, with each plasma torch being aimed directly at the molten stream exiting the delivery system.
16. The apparatus as defined in Claim 15, wherein the torches are annularly disposed with respect to the molten stream.
17. The apparatus as defined in any one of Claims 12 to 16, wherein the molten feed in the crucible is adapted to be heated by induction, which is typically disposed around the crucible.
18. The apparatus as defined in any one of Claims 1 to 3, wherein the metallic powders are adapted to be produced from one of a molten feedstock and a solid feedstock.
19. The apparatus as defined in Claim 18, wherein the plasma source includes an annular plasma torch, and wherein the solid or liquid feedstock is adapted to be fed via a crucible/feed guide through the annular plasma torch.
20. The apparatus as defined in any one of Claims 18 to 19, wherein a pusher is provided for feeding the solid feedstock to the annular plasma torch.
21. The apparatus as defined in Claim 20, wherein the pusher is adapted to feed the solid feedstock through the crucible/feed guide, upstream of the annular plasma torch.
22. The apparatus as defined in any one of Claims 19 to 21, wherein the annular plasma torch includes a set of electrodes put in series and adapted to heat an inert gas to a plasma state and accelerate it to impact the solid feedstock so as to atomize the solid feedstock.

23. The apparatus as defined in any one of Claims 18 to 22, wherein the solid feedstock is substantially in the form of a rod.
24. The apparatus as defined in any one of Claims 22 to 23, wherein the set of electrodes are circularly disposed.
25. The apparatus as defined in any one of Claims 18 to 24, wherein the feedstock is adapted to be preheated with induction or resistively.
26. The apparatus as defined in Claim 25, wherein the induction is disposed around the crucible/feed guide.
27. The apparatus as defined in any one of Claims 4 to 11, wherein the molten feedstock is fed centrally through a ring of plasma torches, connected to a gas channel leading to a single annular supersonic nozzle.
28. The apparatus as defined in any one of Claims 12 to 17, wherein the molten feedstock is fed centrally through a ring of plasma torches, connected to a gas channel leading to their individual respective nozzles focused on an apex.
29. The apparatus as defined in any one of Claims 4 to 17, wherein the molten feed can be obtained either through conductive heating from the plasma plume or by any other means of melting the metal.
30. The apparatus as defined in any one of Claims 4 to 17, wherein the molten feed can be directed through the delivery system, such as a feeding tube, by at least one of gravity, gas pressure and a piston.

31. The apparatus as defined in any one of Claims 1 to 30, wherein supersonic jets of the plasma stream are aimed with an angle such as to push downstream the molten stream.

32. The apparatus as defined in any one of Claims 1 to 31, wherein the plasma source includes an arc plasma torch.

33. The apparatus as defined in any one of Claims 1 to 31, wherein the plasma source includes at least one of inductively-coupled, microwave, and capacitive plasma sources.

34. A process for producing metallic powders from molten feedstock, comprising:

- providing a molten feed;
- delivering the molten feed as a molten stream;
- providing a plasma stream;
- accelerating the plasma stream to a supersonic velocity; and
- impacting the molten stream with a supersonic plasma plume for producing metallic powders.

35. The process as defined in Claim 34, wherein the plasma stream is delivered via at least one plasma source.

36. The process as defined in any one of Claims 34 and 35, wherein the molten feed is delivered, via a liquid feed tube extending from a crucible containing the molten feed, downstream to a location where a supersonic plasma plume is adapted to atomize the molten stream.

37. The process as defined in any one of Claims 34 to 36, wherein the plasma source includes at least two plasma torches connected to a plenum chamber.

38. The process as defined in Claim 37, wherein the plenum chamber is donut-shaped.

39. The process as defined in any one of Claims 37 to 38, wherein outlets of the plasma torches are connected tangentially to force a vortex inside the plenum chamber.

40. The process as defined in any one of Claims 37 to 39, wherein an outlet of the plenum chamber includes a single annular supersonic nozzle aimed towards the molten stream.

41. The process as defined in any one of Claims 37 to 39, wherein an outlet of the plenum chamber includes multiple supersonic holes aimed towards the molten stream.

42. The process as defined in Claim 41, wherein the supersonic holes include nozzles.

43. The process as defined in any one of Claims 41 to 42, wherein the supersonic holes are centrally aimed at the molten stream.

44. The process as defined in any one of Claims 37 to 43, wherein the molten feed in the crucible is adapted to be heated by induction, which is typically disposed around the crucible.

45. The process as defined in any one of Claims 34 to 36, wherein the plasma source includes at least two plasma torches each provided with a cylindrical supersonic nozzle.

46. The process as defined in Claim 45, wherein there are provided at least four plasma torches, disposed symmetrically about the location where supersonic plasma plumes atomize the molten stream.
47. The process as defined in Claim 46, wherein there are provided at least six plasma torches, disposed symmetrically about the location where the supersonic plasma plumes atomize the molten stream.
48. The process as defined in any one of Claims 45 to 47, wherein the plasma torches are arranged in a ring-shaped configuration, with each plasma torch being aimed directly at the molten stream exiting the delivery system.
49. The process as defined in Claim 48, wherein the torches are annularly disposed with respect to the molten stream.
50. The process as defined in any one of Claims 45 to 49, wherein the molten feed in the crucible is adapted to be heated by induction, which is typically disposed around the crucible.
51. The process as defined in any one of Claims 34 to 36, wherein the metallic powders are adapted to be produced from one of a molten feedstock and a solid feedstock.
52. The process as defined in Claim 51, wherein the plasma source includes an annular plasma torch, and wherein the solid or liquid feedstock is adapted to be fed via a crucible/feed guide through the annular plasma torch.
53. The process as defined in any one of Claims 51 to 52, wherein a pusher is provided for feeding the solid feedstock to the annular plasma torch.

54. The process as defined in Claim 53, wherein the pusher is adapted to feed the solid feedstock through the crucible/feed guide, upstream of the annular plasma torch.

55. The process as defined in any one of Claims 52 to 54, wherein the annular plasma torch includes a set of electrodes put in series and adapted to heat an inert gas to a plasma state and accelerate it to impact the solid feedstock so as to atomize the solid feedstock.

56. The process as defined in any one of Claims 51 to 55, wherein the solid feedstock is substantially in the form of a rod.

57. The process as defined in any one of Claims 55 to 56, wherein the set of electrodes are circularly disposed.

58. The process as defined in any one of Claims 51 to 57, wherein the feedstock is adapted to be preheated with induction or resistively.

59. The process as defined in Claim 58, wherein the induction is disposed around the crucible/feed guide.

60. The process as defined in any one of Claims 37 to 44, wherein the molten feedstock is fed centrally through a ring of plasma torches, connected to a gas channel leading to a single annular supersonic nozzle.

61. The process as defined in any one of Claims 45 to 50, wherein the molten feedstock is fed centrally through a ring of plasma torches, connected to a gas channel leading to their individual respective nozzles focused on an apex.

62. The process as defined in any one of Claims 37 to 50, wherein the molten feed can be obtained either through conductive heating from the plasma plume or by any other means of melting the metal.

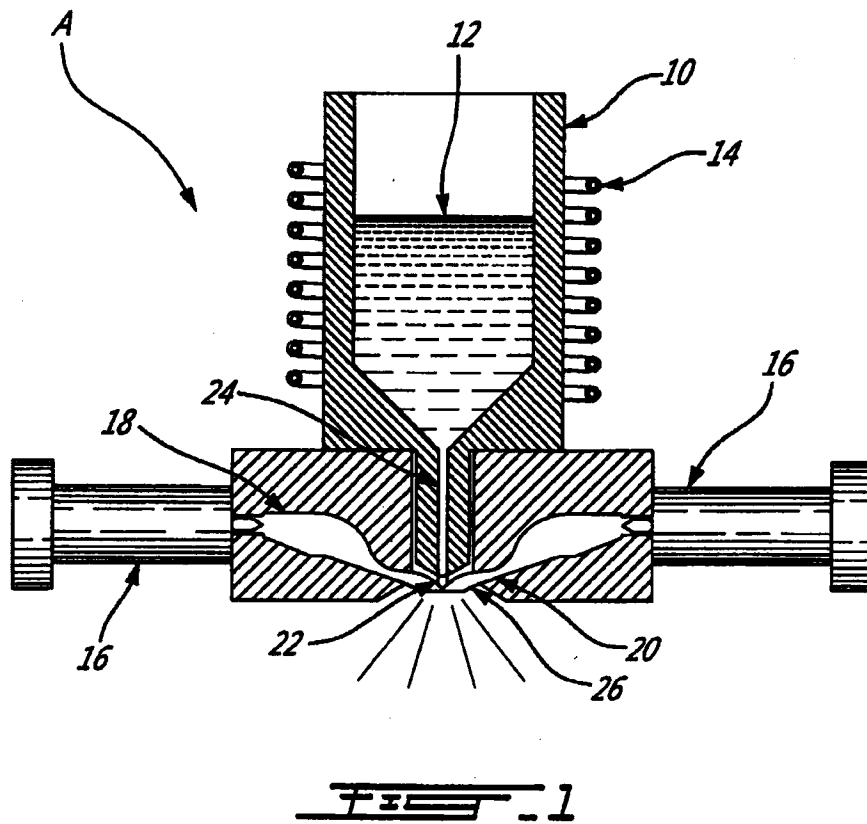
63. The process as defined in any one of Claims 37 to 50, wherein the molten feed can be directed through the delivery system, such as a feeding tube, by at least one of gravity, gas pressure and a piston.

64. The process as defined in any one of Claims 34 to 63, wherein supersonic jets of the plasma stream are aimed with an angle such as to push downstream the molten stream.

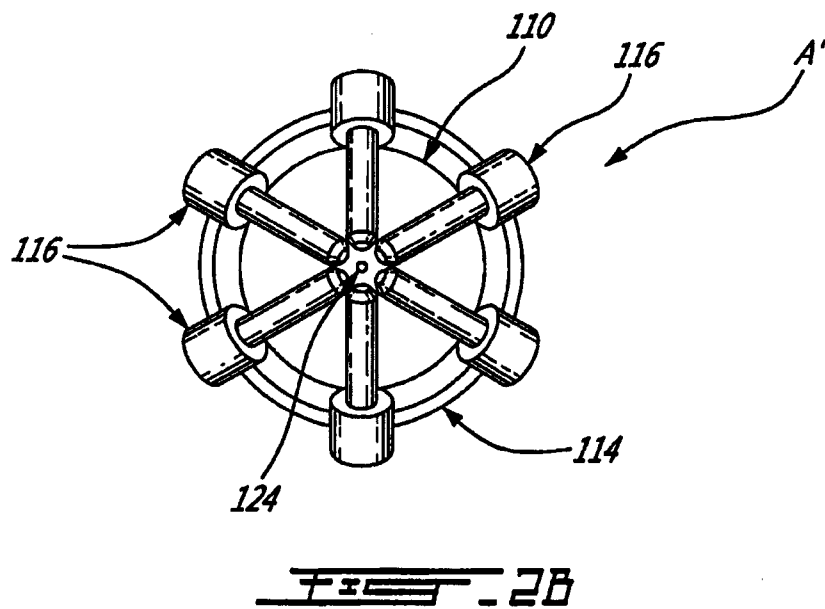
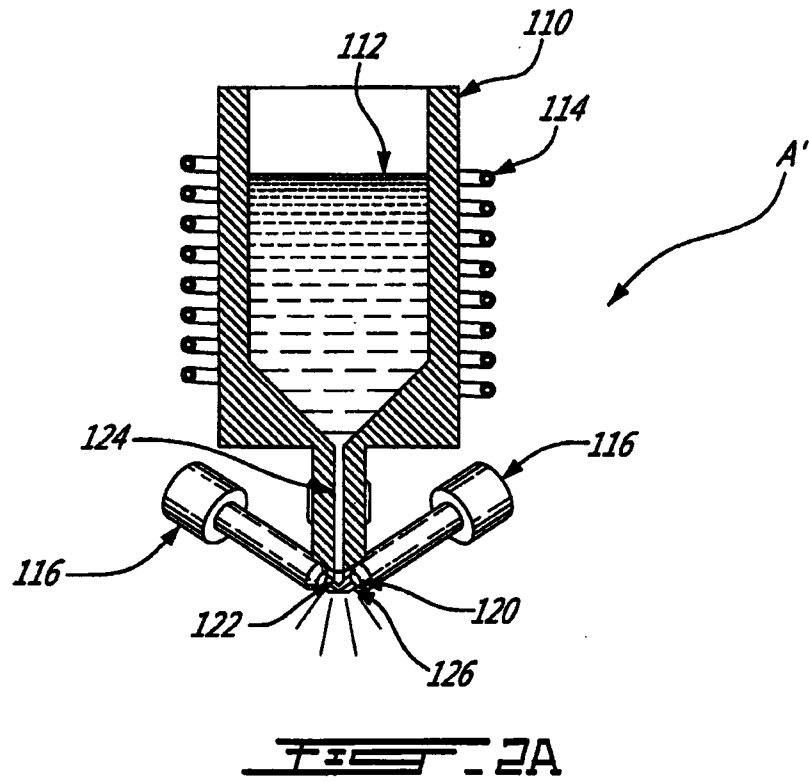
65. The process as defined in any one of Claims 34 to 64, wherein the plasma source includes an arc plasma torch.

66. The process as defined in any one of Claims 34 to 64, wherein the plasma source includes at least one of inductively-coupled, microwave, and capacitive plasma sources.

67. The process as defined in any one of Claims 34 to 66, wherein the atomization process is carried out under an inert atmosphere.



2 / 3



3/3

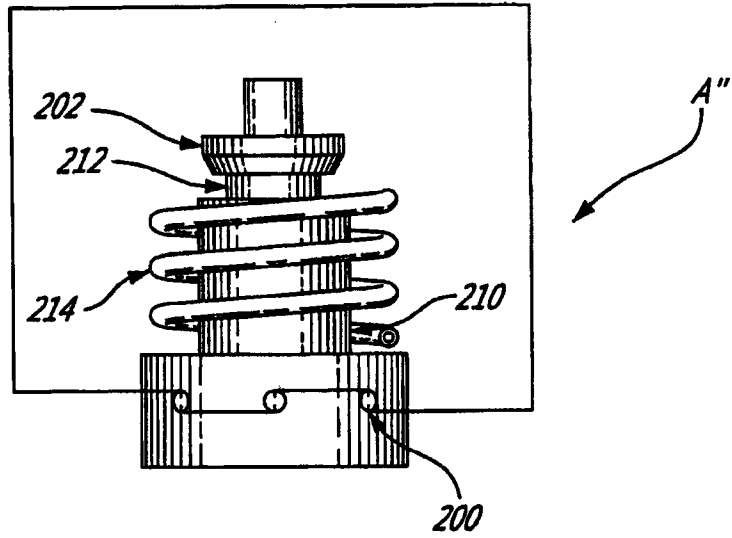


FIG. 3A

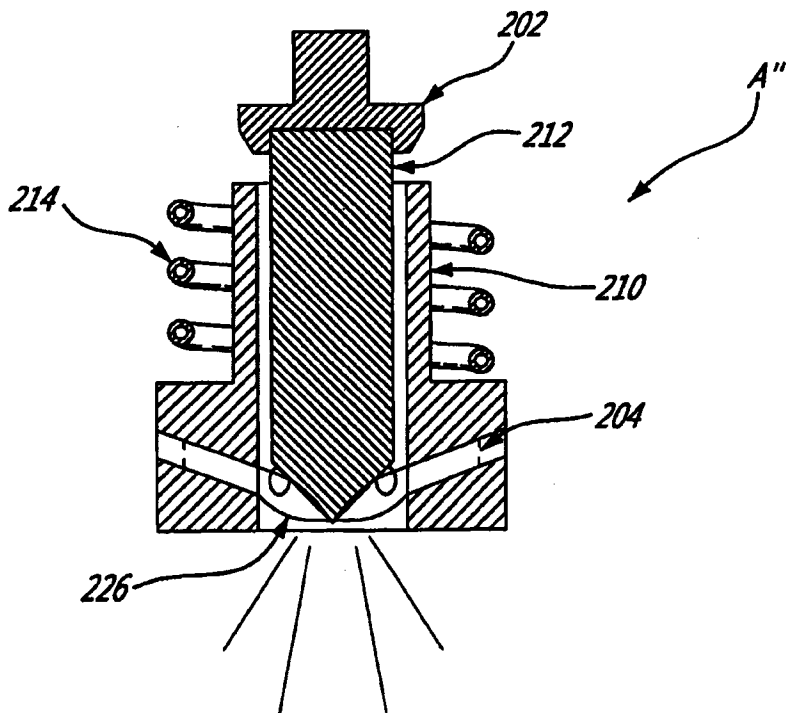


FIG. 3B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2019/000034A. CLASSIFICATION OF SUBJECT MATTER
IPC: **B22F 9/14** (2006.01) , **B22F 9/08** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: B22F*

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Keywords searched

- (plasma atomi* and (molten or melt* or liquid) and (jet or stream or flame) and induct* heat*)
- (plasma torch and tangent* and (vortex or swirl* or whirl* or rotat*) and (flame or jet or stream) and (plenum chamber or press* chamber))

Publication Date: =< 18 March 2019 (18-03-2019)

Databases searched and search strings:

Search #1: Keywords (1) + Publication Date Search #2: Keywords (2) + Publication Date

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA 2,992,303 A1 (LAROUCHE, F. et al.) 26 January 2017 (26-01-2017) Abstract; paragraphs 0038, 0039 & 0083- 0089; claims 1, 12-16 & 19; and Fig. 1.	1-5, 11-26, 28-38, 44-59 & 61-67
Y		1-5, 11-26, 28-38, 44-59 & 61-67
Y	CN 206912255 U (ZHOU, C. et al.) 23 January 2018 (23-01-2018) Abstract; paragraphs 0009, 0017, 0018, 0022, 0023, 0027 & 0028; claim1; and Fig.1.	1-5, 11-26, 28-38, 44-59 & 61-67
A	US 5,228,620 (ANDERSON, I.E. et al.) 20 July 1993 (20-07-1993) Whole document.	Nil
A	WO 2016/191854 A1 (DORVAL DION, C.A. et al.) 8 December 2016 (08-12-2016) Whole document.	Nil

 Further documents are listed in the continuation of Box C. See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
--------------------------------------	--	--------------------------	--

Date of the actual completion of the international search
24 June 2019 (24-06-2019)Date of mailing of the international search report
16 July 2019 (16-07-2019)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Benjamin Chan (819) 639-8445

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2019/000034

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/135075 A1 (BOULOS, M.I. et al.) Whole document.	17 September 2015 (17-09-2015) Nil
A	US 5,023,425 (SEVERANCE, JR., W.S.) Whole document.	11 June 1991 (11-06-1991) Nil
A	US 2013/0273480 A1 (SANTOIANNI, J. et al.) Whole document.	17 October 2013 (17-10-2013) Nil

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2019/000034

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
CA2992303A1	26 January 2017 (26-01-2017)	CA2992303A1 CA2992303C AU2016297700A1 CA3013154A1 CN108025365A EP3325196A1 EP3325196A4 JP2018528328A KR20180056641A US2018214956A1 WO2017011900A1	26 January 2017 (26-01-2017) 21 August 2018 (21-08-2018) 08 March 2018 (08-03-2018) 26 January 2017 (26-01-2017) 11 May 2018 (11-05-2018) 30 May 2018 (30-05-2018) 22 August 2018 (22-08-2018) 27 September 2018 (27-09-2018) 29 May 2018 (29-05-2018) 02 August 2018 (02-08-2018) 26 January 2017 (26-01-2017)
CN206912255U	23 January 2018 (23-01-2018)	None	
US5228620A	20 July 1993 (20-07-1993)	US5228620A CA2068421A1 DE69126296D1 DE69126296T2 EP0504382A1 EP0504382A4 EP0504382B1 JPH05502478A US5125574A WO9205903A1	20 July 1993 (20-07-1993) 10 April 1992 (10-04-1992) 03 July 1997 (03-07-1997) 04 September 1997 (04-09-1997) 23 September 1992 (23-09-1992) 18 November 1993 (18-11-1993) 28 May 1997 (28-05-1997) 28 April 1993 (28-04-1993) 30 June 1992 (30-06-1992) 16 April 1992 (16-04-1992)
WO2016191854A1	08 December 2016 (08-12-2016)	WO2016191854A1 BR112017026248A2 CA2987951A1 CN108025364A EP3302855A1 EP3302855A4 JP2018524478A TW201642974A US2018169763A1	08 December 2016 (08-12-2016) 11 September 2018 (11-09-2018) 08 December 2016 (08-12-2016) 11 May 2018 (11-05-2018) 11 April 2018 (11-04-2018) 05 December 2018 (05-12-2018) 30 August 2018 (30-08-2018) 16 December 2016 (16-12-2016) 21 June 2018 (21-06-2018)
WO2015135075A1	17 September 2015 (17-09-2015)	WO2015135075A1 AU2015230636A1 AU2015230636B2 CA2912282A1 CA3030794A1 CA3039695A1 CN106457180A EP3116636A1 EP3116636A4 JP2017518165A KR20160131060A RU2016139600A RU2016139600A3 US2016175936A1 US9718131B2 US2017106448A1 US9751129B2 US2017326649A1	17 September 2015 (17-09-2015) 20 October 2016 (20-10-2016) 17 May 2018 (17-05-2018) 17 September 2015 (17-09-2015) 17 September 2015 (17-09-2015) 17 September 2015 (17-09-2015) 22 February 2017 (22-02-2017) 18 January 2017 (18-01-2017) 15 November 2017 (15-11-2017) 06 July 2017 (06-07-2017) 15 November 2016 (15-11-2016) 11 April 2018 (11-04-2018) 02 November 2018 (02-11-2018) 23 June 2016 (23-06-2016) 01 August 2017 (01-08-2017) 20 April 2017 (20-04-2017) 05 September 2017 (05-09-2017) 16 November 2017 (16-11-2017)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2019/000034

US5023425A	11 June 1991 (11-06-1991))	US5023425A T114397T AU6080890A AU622385B2 BR9004384A CA2022782A1 CA2022782C CN1053380A CN1028501C DE437915T1 DE69014289D1 DE69014289T2 DE69014289T3 EP0437915A2 EP0437915A3 EP0437915B1 EP0437915B2 FI903867A HU904975D0 HUT56988A IE902775A1 IL95273D0 IL95273A JPH03225727A JPH0570250B2 KR930005883B1 NO903473D0 NO903473L PH26870A PL287337A1 RU2028899C1 US5097111A ZA9006260B	11 June 1991 (11-06-1991) 15 December 1994 (15-12-1994) 18 July 1991 (18-07-1991) 02 April 1992 (02-04-1992) 03 September 1991 (03-09-1991) 18 July 1991 (18-07-1991): 08 February 2000 (08-02-2000) 31 July 1991 (31-07-1991) 24 May 1995 (24-05-1995) 16 January 1992 (16-01-1992) 05 January 1995 (05-01-1995) 01 June 1995 (01-06-1995) 13 July 2000 (13-07-2000) 24 July 1991 (24-07-1991) 18 December 1991 (18-12-1991) 23 November 1994 (23-11-1994) 01 December 1999 (01-12-1999) 18 July 1991 (18-07-1991) 28 January 1991 (28-01-1991) 28 October 1991 (28-10-1991) 17 July 1991 (17-07-1991) 30 June 1991 (30-06-1991) 12 April 1994 (12-04-1994) 04 October 1991 (04-10-1991) 04 October 1993 (04-10-1993) 25 June 1993 (25-06-1993) 07 August 1990 (07-08-1990) 18 July 1991 (18-07-1991) 16 November 1992 (16-11-1992) 29 July 1991 (29-07-1991) 20 February 1995 (20-02-1995) 17 March 1992 (17-03-1992) 29 May 1991 (29-05-1991)
US2013273480A1	17 October 2013 (17-10-2013)	US2013273480A1 US9574770B2 CA2869808A1 CN104302997A CN104302997B EP2839231A1 EP2839231A4 HK1205243A1 RU2014145890A RU2670506C2 SG11201406657XA US2017016619A1 WO2013155625A1	17 October 2013 (17-10-2013) 21 February 2017 (21-02-2017) 24 October 2013 (24-10-2013) 21 January 2015 (21-01-2015) 03 May 2017 (03-05-2017) 25 February 2015 (25-02-2015) 23 December 2015 (23-12-2015) 11 December 2015 (11-12-2015) 10 June 2016 (10-06-2016) 23 October 2018 (23-10-2018) 27 November 2014 (27-11-2014) 19 January 2017 (19-01-2017) 24 October 2013 (24-10-2013)