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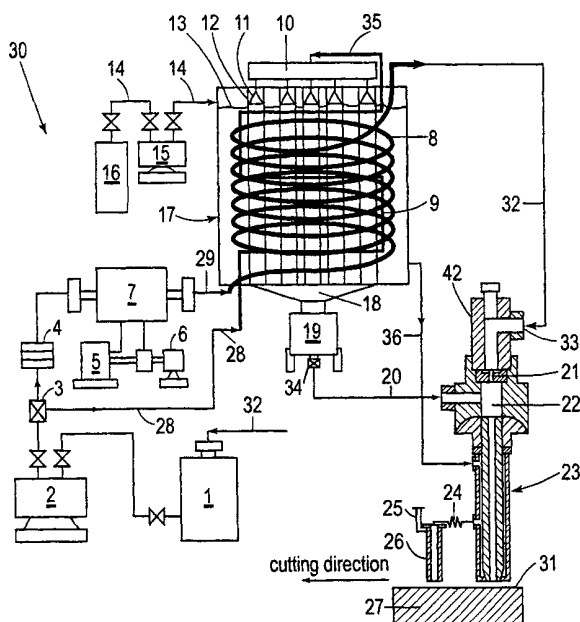
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- (71) Applicant (for all designated States except US): **SWINBURNE LIMITED** [AU/AU]; John Street, Hawthorn, VIC 3122 (AU).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): **SIORES, Elias** [AU/AU]; 2/31 Belford Road, Kew East, VIC 3102 (AU). **CHEN, Frank, Lin** [CN/AU]; 18 Pasadena Crescent, Bentleigh East, VIC 3165 (AU). **MOMBER, Andreas, Wilfried** [DE/DE]; Grabenstrasse 8, D-47057 Duisburg (DE).
- (74) Agents: **PRYOR, Geoffrey, Charles et al.**; Davies Collison Cave, 1 Little Collins Street, Melbourne, VIC 3000 (AU).
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(54) Title: METHOD AND APPARATUS FOR MACHINING AND PROCESSING OF MATERIALS



(57) Abstract: A method of machining and processing a workpiece including the steps of applying a cooling fluid to a surface of the workpiece (27) to generate sudden temperature reduction on said surface, generating ice particles from water droplets, entraining the ice particles in a high pressure stream of a carrier fluid, and directing a jet of said carrier fluid and entrained ice particles at said surface.

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METHOD AND APPARATUS FOR MACHINING  
AND PROCESSING OF MATERIALS

5           This invention relates to a method and apparatus for machining and processing of materials.

          It is known to machine and process various engineering materials with abrasive water jets but the reduction of secondary waste and the application of vanishing abrasive  
10       materials are an important issue in such applications. Some alternative methods have been proposed such as using liquid nitrogen for cutting or mixing mechanically crushed iced particles into a jet suffer from certain drawbacks such as low efficiency, low quality, poor process control and problems associated with materials handling.

15           The object of the present invention is to provide a novel method and apparatus for machining and processing of materials, particularly engineering materials, which offer advantages over the prior art.

          According to the present invention there is provided a method of machining and  
20       processing a workpiece including the steps of applying a cooling fluid to a surface of the workpiece to generate sudden temperature reduction on said surface, generating ice particles from water droplets, entraining the ice particles in a high pressure stream of a carrier fluid, and directing a jet of said carrier fluid and entrained ice particles at said surface.

25           The invention also provides apparatus for machining and processing of materials including cooling means for applying a cooling fluid to a surface of the workpiece, means for generating ice particles from water droplets, mixing means for mixing the ice particles into a high pressure stream of a carrier fluid, and a nozzle for directing a jet of the carrier  
30       fluid and entrained ice particles at said surface.

          The treatment can include a number of different types of treatments including the following treatments:  
          cleaning and decontamination of engineering surfaces  
35       profiling of engineering surfaces

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5 deburring of engineering materials  
cutting of engineering materials  
piercing and drilling of engineering materials  
milling of engineering materials  
turning of engineering materials  
polishing of engineering materials  
assisting in conventional materials processing methods  
removing paint or graffiti from surfaces  
and any combination of these.

10

Preferably, the cooling fluid is liquid nitrogen.

Preferably further, the ice particles are in the range 100 to 300 microns.

15 Preferably the water flow rate is in the range 1 to 2 litres per minute and preferably 1.2 litres per minute.

Preferably the ice flow rate is in the range 100 to 300 grams of ice per minute and typically 240 grams of ice per minute.

20

Preferably the ratio of ice mass to water jet mass is in the range 15% to 25%.

Preferably the ratio of ice volume to water volume flow rate is in the range 16% to 27%.

25

Preferably the water pressure is in the range 2000 to 4000 bar.

The invention will now be further described with reference to the accompanying drawings, in which:

30 FIGURE 1 is a schematic diagram of a cryogenic jet system incorporating the invention;

FIGURE 2 is a more detailed schematic diagram of a heat exchanger;

FIGURE 3 is a more detailed cross-sectional view through one form of nozzle;

FIGURE 4 is a more detailed cross-sectional view through a second form of nozzle;

35 and

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FIGURE 5 is a graph showing variation of cutting speed versus cutting thickness for different materials.

Figure 1 diagrammatically illustrates a cryogenic jet system 30 having a cutting  
5 nozzle 23 for directing a jet of high velocity ice and water at a workpiece 27. The jet can  
be used for treating the workpiece 27 in a variety of ways including cleaning and  
decontamination, profiling, deburring, cutting, piercing and drilling, milling, turning,  
polishing, and removing paint or graffiti from the workpiece. As will be described in more  
detail below, the surface 31 of the workpiece to be treated is pre-cooled prior to application  
10 of the water/ice jet from the nozzle 23.

The system shown in Figure 1 includes a water treatment unit 1 for coarse filtering  
of the water, which receives water from an inlet line 32. The outlet of the water treatment  
unit 1 is coupled to a booster pump 2, the outlet of which is connected to a water high  
15 pressure intensifier 7 through a filter 4 and split valve 3. An hydraulic pump motor 6 is  
provided to drive an hydraulic radial displacement pump (not shown) in the intensifier 7.  
An oil reservoir 5 is provided as part of the hydraulic fluid circuit for the pump motor 6.  
The outlet of the intensifier 7 is coupled to a high pressure water line 29. Typically, the  
temperature of the water at this point is about 45°C and the pressure in the range 2000 to  
20 4000 bar.

The system includes a main heat exchanger 17 which performs a variety of  
functions, as will be explained in more detail below. The heat exchanger 17 contains  
liquid nitrogen which is supplied by a liquid nitrogen delivery line 14 which is coupled to a  
25 liquid nitrogen storage tank 16 via a cryogenic pump 15.

The high pressure water line 29 is coupled to the inlet of a high pressure heat  
exchanger coil 8 which includes a plurality of convolutions within the exchanger 17,  
typically about 7. The outlet of the coil 8 is coupled to an inlet line 32 which is connected  
30 to an inlet 33 of the cutting nozzle 23. Typically the temperature of the water supplied to  
the inlet 33 is about 5°C and the pressure is in the range 2000 to 4000 bar.

Located within the core of the heat exchanger 17 is a plurality of vertically  
extending finned tubes 12, the exterior surfaces of which are exposed to the liquid nitrogen  
35 for cooling purposes. Water droplet spray nozzles 11 are provided at the tops of each of  
the tubes 12 for spraying water droplets into the interior of the tubes. The water droplets

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quickly freeze into ice particles which are collected in a funnel 18 for delivery to an insulated hopper 19, the output of which has coupled thereto a metering system 34 for controlling the rate of discharge of ice particles from the hopper. The water droplet spray nozzles 11 are supplied with water from a distributing chamber 10 which receives cooled  
5 water from a low pressure heat exchanger coil 9 via a supply line 35. The input to the low pressure coil 9 is coupled to a supply line 28 which receives water from the split valve 3. Preferably the ratio of the volume of water to the high pressure coil 8 to the low pressure coil 9 is 1:0.25. The water supplied to the distributing chamber 10 is typically at 5°C.

10 The distributing chamber 10 may be replaced by a pneumatically or electrically driven split valve which is arranged to open and close lines which lead to the nozzles 11 for controlling the flow rate of water thereto.

Preferably the spray nozzles 11 can be controlled so as to vary the size of the water  
15 droplets they produce. Conventional water spraying nozzles can be used. Alternatively, air driven spraying devices can be used. Thirdly, electrically or ultrasonically driven sprayers could also be utilised. Whatever the technique utilised, the nozzles 11 are adjusted so as to produce a controlled size of water droplets which produce ice particles in the range 100 to 300 microns. Typically the temperature of the ice particles in the hopper  
20 19 or delivered to the nozzle 23 is in the range -10°C to -5°C.

A liquid nitrogen supply line 36 is connected from the bottom of the heat exchanger 17 to supply liquid nitrogen to the nozzle 23, as will be described in more detail below.

25

The heat exchange tank 17 is preferably cylindrical having a sidewall which typically is of 1.5 metres diameter. The high pressure heat exchange coil preferably has about six to ten convolutions in the liquid nitrogen in the vessel. The low pressure coil 9 has only about three convolutions in the liquid nitrogen so as to ensure that the water does  
30 not freeze prior to delivery to the spray nozzles 11. The finned copper tubes 12 are located within the cylindrical region in the centre of the annular vessel 17 and are surrounded by liquid nitrogen. This causes rapid freezing of the water droplets from the nozzles 11. Typically, the length of the vessel 17 and therefore the lengths of the tubes 12 is about 2 metres.

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Figure 3 illustrates the cutting nozzle 23 in more detail. The nozzle 23 has a main body 40 within which is formed a mixing chamber 22. The main body 40 is connected to a water jet on/off control valve 42 which includes the inlet 33, as shown. Water from the valve 42 enters the chamber 22 via a water jet orifice 21. Preferably the diameter of the orifice 21 is in the range 0.3-.5mm. Ice particles from the hopper 19 are delivered via a delivery hose 20 to an ice inlet 43. Expansion of high velocity water in the mixing chamber 22 causes entrainment of and mixing of the ice particles into the stream of high pressure water in the chamber 22. The nozzle 23 includes a mixing tube 44 having a discharge opening 46 at its lower end for discharge of the high velocity water and ice particles directed towards the surface 31 of the workpiece 27. Typically both the body 40 and mixing tube 44 are made from stainless steel. The mixing tube 44 may have an outside diameter of say 5mm. The bore within the mixing tube 44 has a diameter in the range 1.2 to 1.5mm. Because the orifice 21 is very narrow, it produces a very high velocity of water entering the mixing chamber 22 and accordingly the velocity of the water and ice particles are normally in the range from 400 to 700 metres per second. The mixing tube 44 is surrounded by a jacket 48 which includes an inlet 50 and outlet 52. This enables circulation of liquid nitrogen from the line 36 within the jacket for maintaining the tube 44 at a lower temperature. A flexible nitrogen hose 24 extends between the outlet 52 and a focusing tube 26 which directs a controlled stream of liquid nitrogen at the surface 31 for pre-cooling of the surface prior to application of the water jet/ice particles. It will be noted that the tube 26 is upstream of the nozzle 23 so that the workpiece is rapidly cooled prior to having the jet of water and ice particles infringing thereon.

Optimally, the temperature of the ice particles at the point of discharge from the discharge opening 46 would be about -5°C. The temperature of the high pressure water at discharge would optimally be in the range from 1°C to 2°C. The precooling of the workpiece surface optimally pre-cools the surface temperature of the workpiece to be in the range from say -50°C to -20°C. Cooling of the workpiece so that the surface temperature thereof is in the aforementioned range, makes the workpiece relatively more brittle and therefore more suitable for being eroded by the ice particles in the water jet.

Normally there would be relative movement between the nozzle 23 and the workpiece 27. This is most conveniently arranged by having the nozzle 23 generally stationary and moving the workpiece but this is not necessarily so. Further, in some circumstances it may be desirable to be able to move the focusing tube 26 relative to the mixing tube 44 so as to vary the manner in which the cooling by the liquid nitrogen occurs.

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Figure 4 illustrates an alternative cutting nozzle 60. The same reference numerals are used to denote parts which are the same as or correspond to those of the embodiment shown in Figure 3. The main difference between this embodiment and that shown in Figure 3 is that the tube 26 is eliminated and the outlet for the liquid nitrogen jacket 48 is in the form of an annular orifice 64 which surrounds the opening 46. As with the previous embodiment, liquid nitrogen from the orifice 64 is directed at the surface 31 of the workpiece in order to pre-cool the surface prior to application of the water jet/ice particles thereto.

10 As indicated above the method and apparatus of the invention can be used for a number of different processes, including cutting. Figure 5 diagrammatically shows the cutting speed versus thickness of material for several different types of material. The line 72 represents plexiglass or acrylic. The line 74 represents aluminium and the line 76 represents stainless steel.

15 In accordance with the invention, very accurate surface treatments can be carried out, such as accurate cutting and fine surface finishes can be achieved. Also the process uses only water and liquid nitrogen and therefore waste materials are relatively benign (except for particles of the workpiece 27 which are necessarily produced).

20 Many modifications will be apparent to those skilled in the art without departing from the spirit and scope of the invention.

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CLAIMS:

1. A method of machining and processing a workpiece including the steps of applying a cooling fluid to a surface of the workpiece (27) to generate sudden temperature reduction on said surface, generating ice particles from water droplets, entraining the ice particles in a high pressure stream of a carrier fluid, and directing a jet of said carrier fluid and entrained ice particles at said surface.
2. A method as claimed in claim 1 wherein the size of the ice particles is in the range from 100 to 300 microns.
3. A method as claimed in claim 1 or 2 wherein said carrier fluid is a high pressure stream of water.
4. A method as claimed in claim 3 wherein the flow rate of said high pressure stream of water is in the range of 1 to 2 litres per minute.
5. A method as claimed in claim 3 or 4 wherein the ice particles are entrained in said high pressure stream of water such that the flow rate of ice particles is in the range 100 to 300 grams per minute.
6. A method as claimed in claim 3, 4 or 5 wherein the ratio of ice particle mass to water mass in said high pressure stream of water is in the range 15% to 25%.
7. A method as claimed in claim 3, 4 or 5 wherein the ratio of ice particle volume to water volume in said high pressure stream of water is in the range 16% to 27%.
8. A method as claimed in any one of claims 3 to 7 wherein the pressure of said high pressure stream of water is in the range of 2000 to 4000 bar.
9. A method as claimed in any one of claims 1 to 8 wherein said cooling fluid is liquid nitrogen.

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10. A method as claimed in any one of claims 1 to 9 wherein the step of directing a jet of said carrier fluid includes the steps of locating a tip of a discharge nozzle adjacent to said surface and causing relative movement between the surface and the nozzle.
- 5 11. A method as claimed in claim 10 wherein the nozzle includes a mixing chamber and wherein the ice particles and said carrier fluid are separately supplied to the mixing chamber and said entraining of the ice particles occurs in said mixing chamber.
12. A method as claimed in claim 11 wherein said cooling fluid also cools said nozzle.
- 10 13. A method as claimed in any one of claims 1 to 12 wherein said processing of the workpiece includes cleaning, decontamination, deburring, cutting, piercing, drilling, milling, turning, polishing and/or paint removal.
- 15 14. A method as claimed in any one of claims 3 to 8 wherein the temperature of the water in said jet is in the range 1°C to 2°C and the temperature of the ice particles is about -5°C.
15. A method as claimed in claim 14 wherein the surface temperature of the workpiece
- 20 is cooled to a temperature in the range -50°C to -20°C.
16. Apparatus for machining and processing of materials including cooling means (26,64) for applying a cooling fluid to a surface of the workpiece (27), means (11,12) for generating ice particles from water droplets, mixing means (22) for mixing the ice particles
- 25 into a high pressure stream of a carrier fluid, and a nozzle (23) for directing a jet of the carrier fluid and entrained ice particles at said surface.
17. Apparatus as claimed in claim 16 wherein the apparatus includes a cutter body (40) and wherein the mixing means comprises a mixing chamber (22) in the body and wherein
- 30 the nozzle includes a discharge pulse (44) one end of which communicates with said mixing chamber and the other end of which has a discharge opening (46) from which jet is

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directed at the workpiece.

18. Apparatus as claimed in claim 17 wherein said means for generating ice particles from water droplets includes water supply means (32,2) for supplying water to spray  
5 nozzles (11) located in heat transfer tubes (12) and collection means (18) for collecting frozen water droplets formed in said heat transfer tubes.

19. Apparatus as claimed in claim 18 wherein a delivery hose (20) extends from said collection means (18) to said mixing chamber to deliver said frozen water droplets to said  
10 mixing chamber.

20. Apparatus as claimed in any one of claims 17, 18 or 19 wherein the cutter body includes a carrier fluid inlet (33) to which a high pressure water supply is connected, said apparatus including a water jet orifice (21) between said inlet and mixing chamber (22),  
15 the arrangement being such that said high pressure water expands after passing through said water jet orifice and entrains said frozen water droplets therein for discharge through said discharge tube.

21. Apparatus as claimed in claim 20 wherein the cooling means operates to discharge  
20 nitrogen from a supply of liquid nitrogen (16) towards said surface.

22. Apparatus as claimed in claim 21 wherein the discharge tube (44) is located within a jacket (46) through said nitrogen passes prior to delivery to said cooling means.

23. Apparatus as claimed in claim 22 wherein the cooling means (26) includes a  
25 nitrogen discharge tube (26) located adjacent to said discharge tube (44).

24. Apparatus as claimed in claim 23 wherein the cooling means includes an orifice (64) in said jacket.

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25. Apparatus as claimed in any one of claims 22 to 24 wherein said heat transfer tubes are located in a heat exchanger vessel and wherein the vessel has an inlet for receipt of liquid nitrogen from said supply of liquid nitrogen and an outlet which delivers liquid nitrogen to said jacket.

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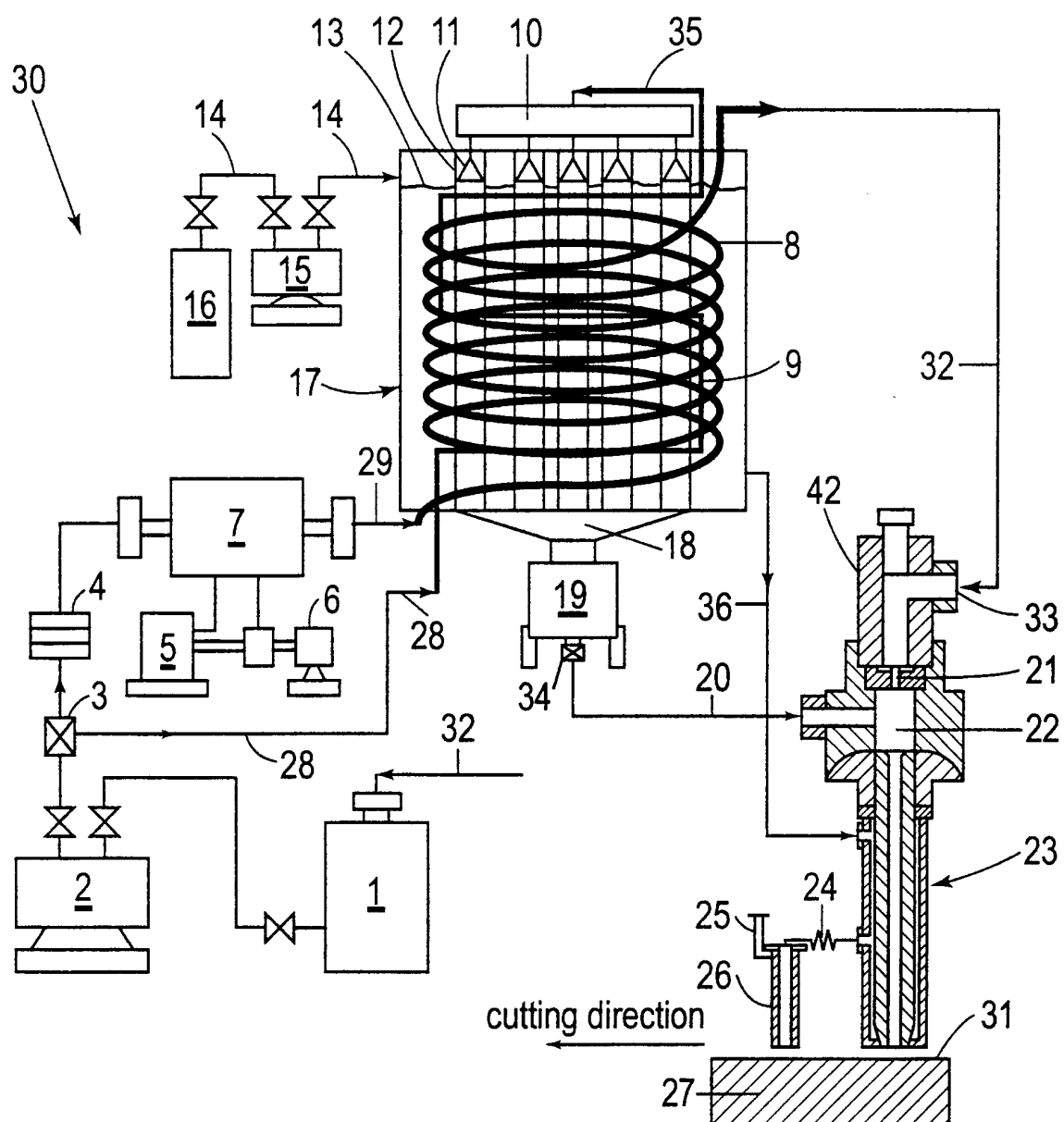
26. Apparatus as claimed in claim 25 wherein the apparatus includes a high pressure water pump (7) for receiving water from said water supply means (32,2), said pump having an outline line (29) which passes through said vessel for cooling the high pressure water prior to delivery to said carrier fluid inlet (33).

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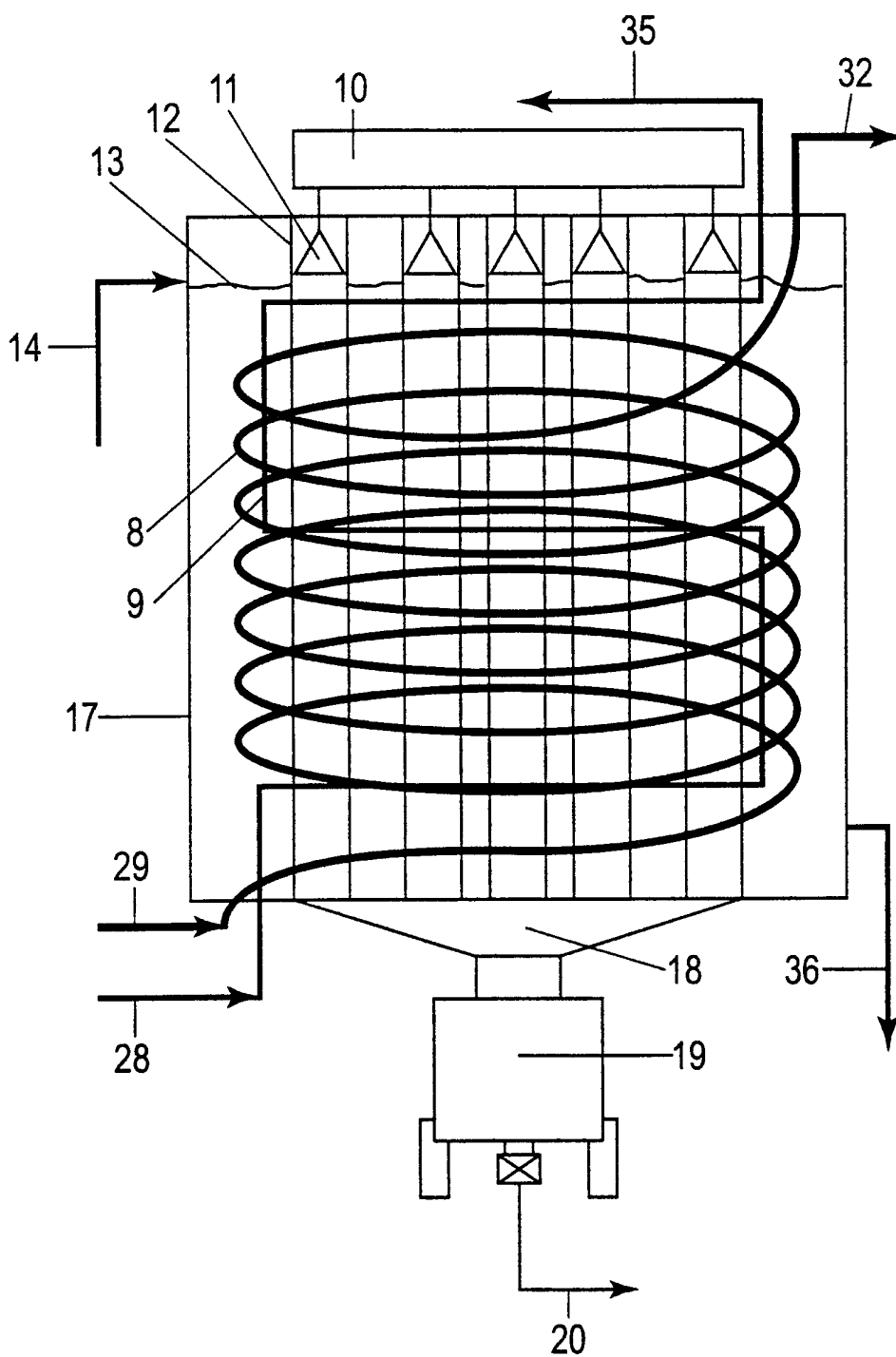
27. Apparatus as claimed in claim 25 or 26 wherein the water supply means (32,3) is coupled to said spray nozzles via a low pressure water line which passes through said vessel so that water delivered to the spray nozzles is cooled in said vessel.

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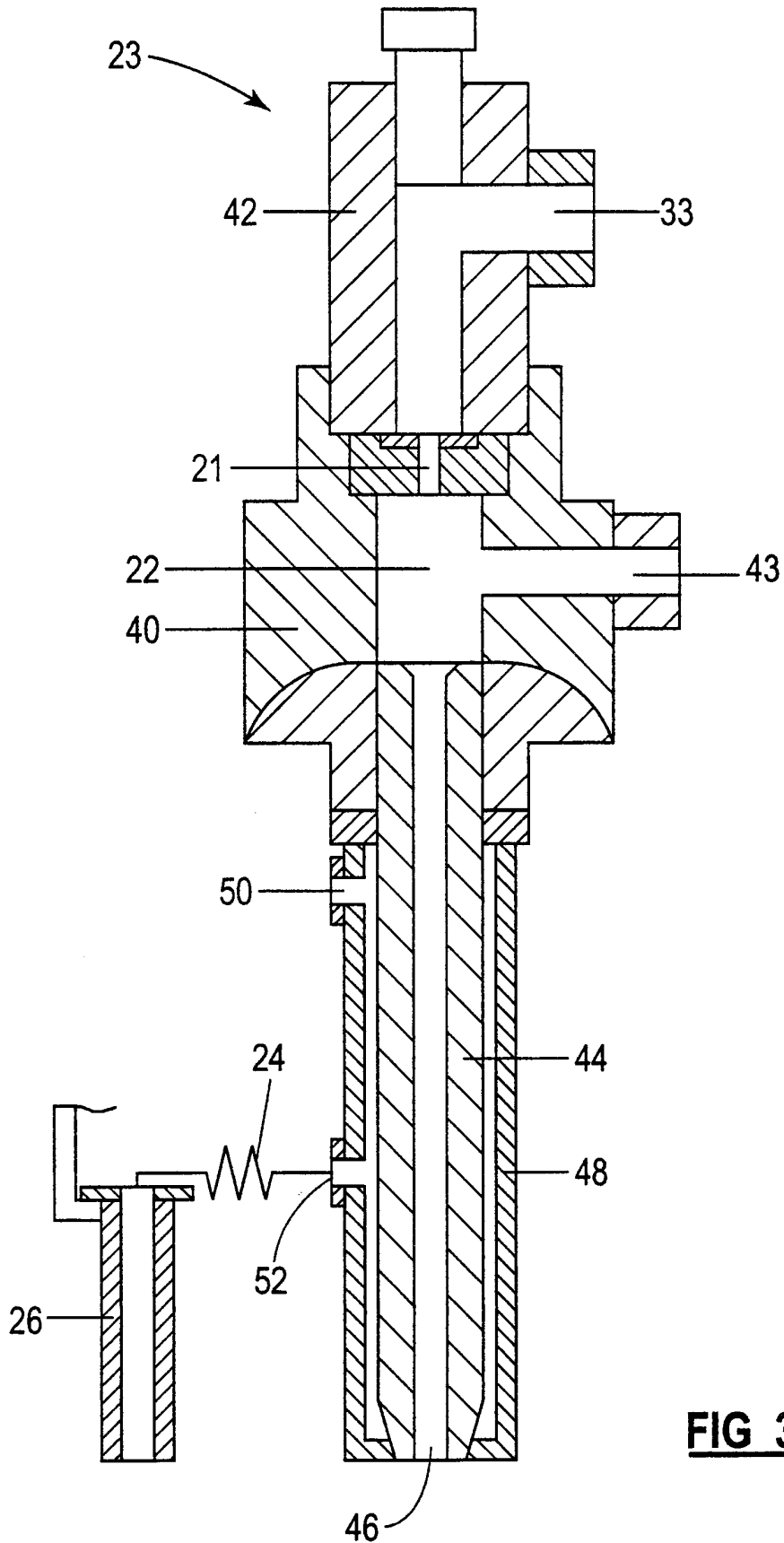
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**FIG 1**

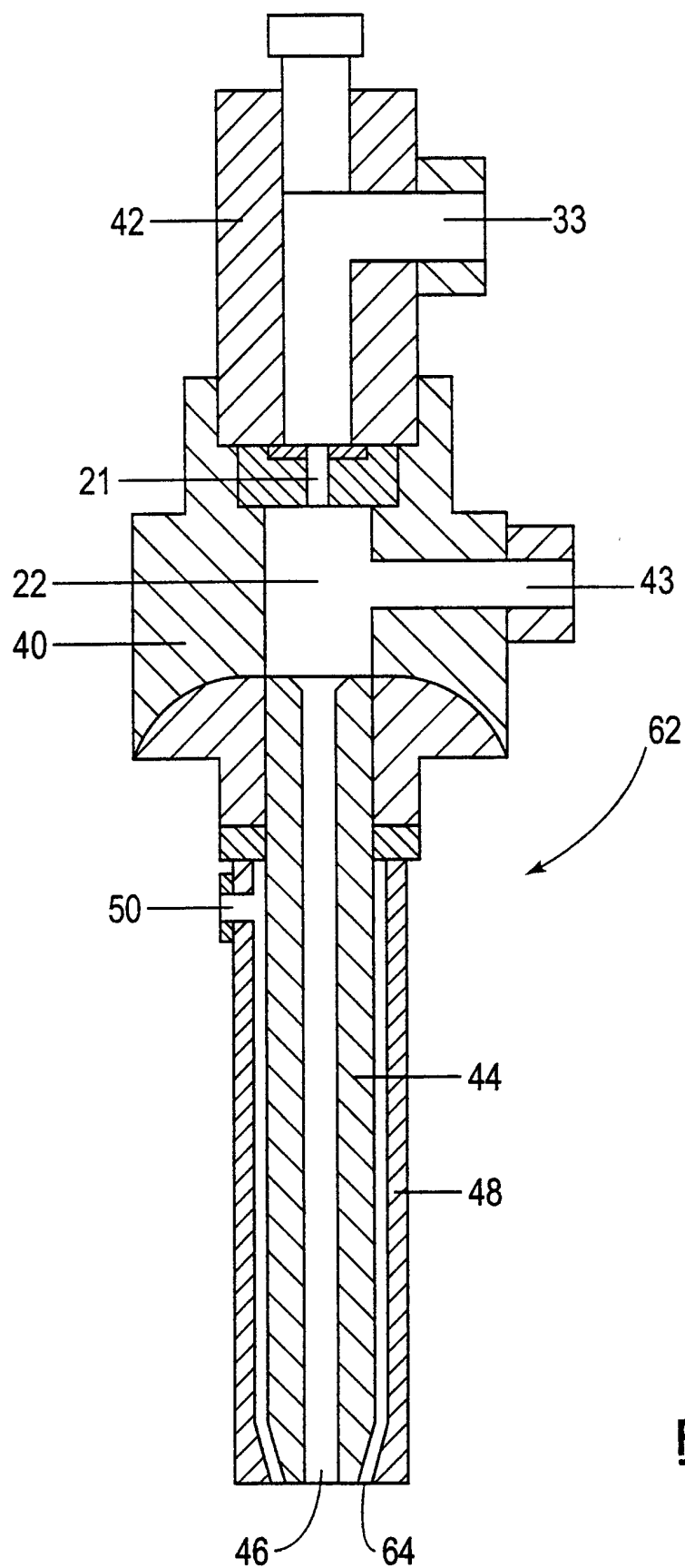
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**FIG 2**

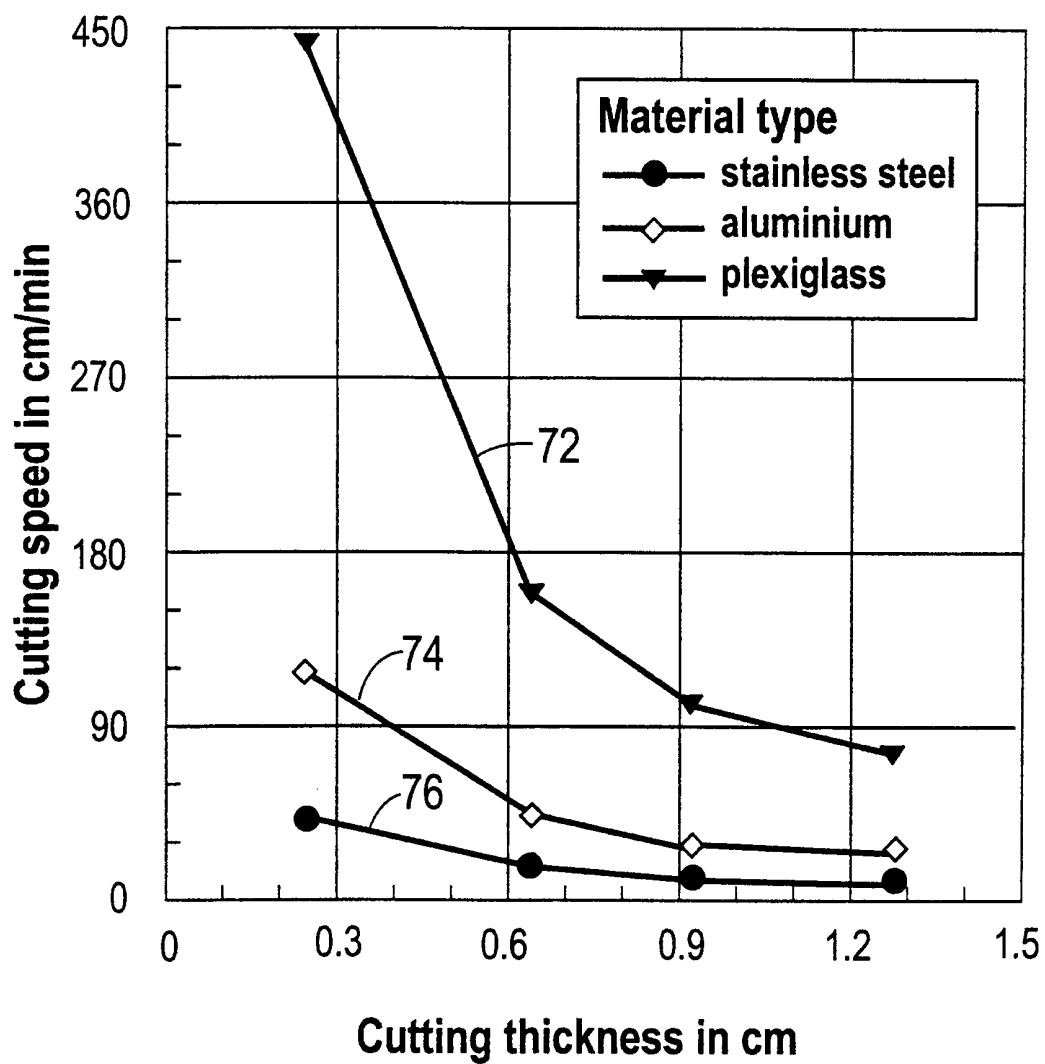
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**FIG 4**

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**FIG 5**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU 00/00837

**A. CLASSIFICATION OF SUBJECT MATTER**Int. Cl. <sup>7</sup>: B24C 1/00, 3/00, B26F 1/26

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: B26F 1/26 B24 C 1/00, 3/00

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

AU; IPC AS ABOVE

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

DWPI: ICE OR FROZEN OR FREEZ+

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4932168 A (TADA ET AL) 12 June 1990 abstract and figure	1-27
Y	US 5785581 (SETTLES) 28 July 1998 abstract and figure	1-27
Y	GB 1397102 A (CARRIER DRYSYS LIMITED) 11 June 1975 Page 2 lines 95-125	1-27

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

\* Special categories of cited documents:

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Date of the actual completion of the international search

31 July 2000

Date of mailing of the international search report

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Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE  
PO BOX 200, WODEN ACT 2606, AUSTRALIA  
E-mail address: pct@ipaaustralia.gov.au  
Facsimile No. (02) 6285 3929

Authorized officer

D.G. FRY

Telephone No : (02) 6283 2130

## INTERNATIONAL SEARCH REPORT

International application No.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5283989 A (HISASUE ET AL.) 8 February 1994 Column 2 lines 56-68	1-27
Y	WO 89/10522 A (COMMISSARIAT A L'ENERGIE ATOMIQUE) 2 November 1989 Abstract	1-27
Y	EP 316264 A (HOWALDTSWERKE-DEUTSCHE WERFT AG) 17 May 1989 Abstract	1-27
Y	DE 19603141 A (CHRSZASZCZAK) 31 July 1997 Abstract	1-27
Y	GB 2077156 A (MANSFIELD) 16 December 1981 Entire document	1-27
	Note: Any one of the first six documents can be combined with either of the last two documents with relevance to the same claims	

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
**PCT/AU 00/00837**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report			Patent Family Member			
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DE	19603141	NONE				
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						END OF ANNEX