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- as to the identity of the inventor (Rule 4.17(i))
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
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(54) Title: AN APPARATUS FOR PRODUCING MATERIAL FOAM FROM A MATERIAL AND METHODS THEREOF

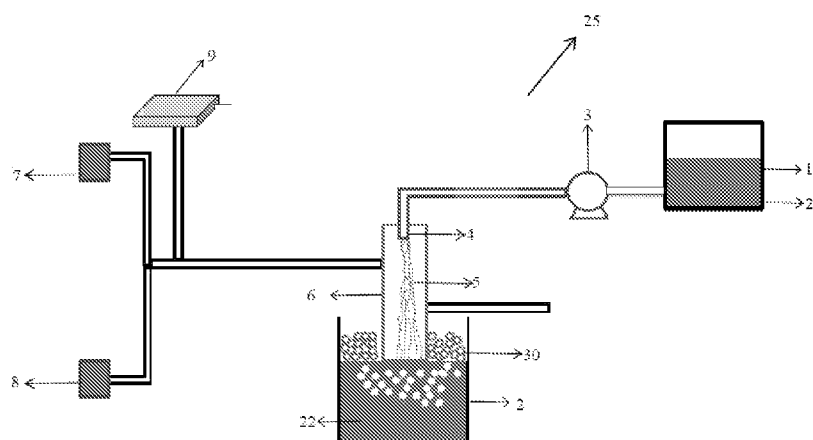


FIG.1

(57) Abstract: The present invention demonstrates a novel method and an apparatus for producing material foam by injecting a jet of molten material into a pool of molten material. Bubbles are created through air entertainment by the impinging jet.



FIELD OF THE INVENTION

[001] The present invention relates to an apparatus and method of producing a material foam, specifically to an apparatus and method of producing a material foam by injecting a jet of material melt into a pool of material melt, wherein the bubbles are created through air entrainment by the impinging jet.

BACKGROUND OF THE INVENTION

[002] Material foams such as metal foams are potential material for lightweight structural application and energy absorption applications. In terms of starting material, there are mainly two ways to produce metal foams: from metal powders and from metallic melts. They are known as the powder metallurgy route and the melt route respectively. In the melt route of foam processing bubbles are created by introducing gas inside a molten metal. This can be performed several ways.

[003] US4713277, teaches a method of adding a blowing agent (e.g., TiH_2) in the molten metal to produce metal foams. It dissociates at high temperature and produces gas resulting in bubble formation. Addition of Ca and TiH_2 with aluminum melt combined with stirring proved to be faster way of production.

[004] US4973358 teaches yet another method of directly injecting gas into molten metal to produce foam. Introduction of gas into a metallic composite

(containing ceramic particles) generates foam at the surface of the melt.

5 **[005]** A different way of gas injection that leads to foams with excellent uniformity of cell sizes is also known (D. Leidlmeier, H.P. Degischer, H.J. Flankl, Development of a foaming process for particulate reinforced aluminum melts, Advanced Engineering Materials, 2002, 4: p. 735-740.).

10 **[006]** By casting the foam into molds, complex-shaped foamed parts can be manufactured. This type of foam is called Metcomb.

15 **[007]** US9168584 teaches the use of oscillation induced by longitudinal waves to separate bubbles from the gas-injecting nozzle.

20 **[008]** While producing foam from metallic melt, bubbles are introduced in the melt either by injecting gas into the melt through a nozzle or by add-mixing a chemical blowing agent which dissociates at high temperature and releases gas. It is challenging to keep the bubble size to a small size while injecting gas into a melt. This in turn results in an increase in average bubble/cell size. When a chemical blowing agent is used, it increases
25 the cost of the product because of the cost of the blowing agent. Moreover, a chemical blowing agent often results in non-uniform pore size distribution because of improper mixing of the blowing agent and rapid dissociation of it when it comes in contact
30 with the melt. A chemical blowing agent also often introduces defects in the solidified foam structure

during solidification. In the melt route, an important aspect to take care is the stability of the foam while it is in liquid state. For this, ceramic particles are either added or created in the melt. These ceramic particles result in brittleness which is not a desirable property in terms of energy absorption application.

[009] Therefore, it is an object of the invention to disclose an efficient, economic and simple apparatus and method to produce material foams from molten metal to produce metal foam by injecting melt into a metallic melt.

15 SUMMARY OF THE INVENTION

[0010] To meet the objects of the invention and overcome the disadvantages of the prior art it is disclosed herein, a method of producing a material foam from one or more materials comprises the steps of:

20 providing a temperature controlled first crucible capable of holding a first liquid material, the said first crucible adapted to prepare the first liquid material in-situ or receiving prepared first liquid material from a melting source;

25 providing a temperature controlled second crucible capable of holding a second liquid material, the said second crucible has at least a part of its volume filled with the second liquid material;

30 providing a means to transfer the first liquid material from the first crucible to the second

crucible through a nozzle, characterized in that, on opening of the nozzle a jet of first liquid material from the first crucible impinges on the second liquid material in the second crucible to produce a foam; and

5 scrapping the material foam by a scrapper and loading it to handling means.

It is disclosed here an apparatus for producing material foam comprising of:

10 a temperature controlled first crucible capable of holding a first liquid material, the said first crucible is adapted to prepare the first liquid material in-situ or receiving prepared first liquid material from a melting source;

15 a temperature controlled second crucible capable of holding the second liquid material, the said second crucible has at least a part of its volume filled with the second liquid material;

20 a means to transfer the first liquid material from the first crucible to the second crucible through a nozzle, characterized in that, on opening of the nozzle a jet of the first liquid material from the first crucible impinges on the second liquid material in the second crucible to produce foam;

25 and

 a means for scrapping the material foam by a scrapper and loading it to handling means.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] **Fig.1** shows the schematic representation of an embodiment of the foam forming apparatus.

5 **FIG 2** shows the schematic representation of an embodiment of the foam forming apparatus.

Fig.3 shows the aluminum foam produced by this method.

Fig.4 shows the X-ray tomographic reconstruction of 2D section of two aluminum foams.

10

DETAILED DESCRIPTION OF THE INVENTION

[0012] The invention and its various embodiments are better understood by reading the description along with the accompanying drawings which appear
15 herein for the purpose of illustration only and does not limit the invention in any way.

[0013] Referring to **FIG.1**, a schematic representation of an exemplary apparatus **(25)** of
20 the invention is shown. It comprises a first crucible **(1)**, a second crucible **(2)**. The crucibles **(1,2)** are high temperature crucibles and capable of handling liquid materials, such as molten metals or alloys or metal matrix composites or polymers or
25 slurry of ceramics. Each of these crucibles may be kept inside a high temperature furnace to control their temperature. The first crucible **(1)** and second crucible connected to each other through a pump **(3)** and nozzle **(4)**. The nozzle **(4)** is attached
30 with a valve to allow the molten material **(20)** to come out as a jet **(5)**. The second crucible **(2)** may

also be a movable crucible that can be moved up and down with the help of a motor.

5 **[0014]** The nozzle **(4)** in the first crucible may optionally be surrounded by a hollow tube **(6)**. The hollow tube **(6)** may be made of steel. This hollow tube **(6)** is equipped with a gas inlet and a gas outlet. The gas inlet is connected to a tube which is connected to a first gas **(7)**, this gas may be an
10 inert gas, and a second gas **(8)** such as oxygen **or air**. The gas inlet is also connected to an oxygen content measuring device **(9)**. This oxygen content measuring device **(9)** is used to know the level of oxygen in the surrounding of the material jet **(5)**.

15 **[0015]** Material ingots are kept in both crucibles **(1,2)** and melted. Both crucibles are connected to each other through a pump **(3)** and nozzle **(4)**. The pump **(3)** pumps the first molten
20 material **(20)** from the first crucible **(1)** to the second crucible **(2)** through the nozzle **(4)**. When the nozzle **(4)** is opened, a material jet **(5)** comes out from the first crucible **(1)** and impinges on the surface of the second molten material **(22)** kept in
25 the second crucible **(2)**. The jet **(5)** entrains gas that is present in the atmosphere surrounding the jet **(5)** while impinging on the surface of the second molten material **(22)** kept in the second crucible **(2)**. In this way bubbles are created in the second
30 crucible **(2)**. These bubbles rise to the surface of

the melt due to buoyancy, and create foam **(30)** at the surface of material kept in the second crucible **(2)**. Subsequently, the foam **(30)** is removed by a metallic scrapper and stored separately.

5

[0016] The first liquid material **(20)** may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of polymers. The first liquid material **(20)** may also
10 be slurry of ceramics

[0017] The second liquid material **(22)** may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of
15 polymers. The second liquid material **(22)** may also be slurry of ceramics

[0018] Referring to **FIG.2**, a schematic representation of an exemplary apparatus **(25)** of
20 the invention is shown. It comprises a first crucible **(1)**, a second crucible **(2)**. The crucibles **(1,2)** are high temperature crucibles and capable of handling liquid materials, such as molten metals or alloys or metal matrix composites or polymers or
25 slurry of ceramics. Each of these crucibles may be kept inside a high temperature furnace to control their temperature. The first crucible **(1)** is fitted with a nozzle **(4)** and a gas-tight lid having an inlet at the top. The nozzle **(4)** is attached with
30 a valve to allow the molten material **(20)** to come out as a jet **(5)**. The second crucible **(2)** may also

be a movable crucible that can be moved up and down with the help of a motor. The inlet of the lid assembly of the first crucible is connected to a gas source (10), preferably an inert gas, equipped with a pressure regulator.

[0019] The nozzle (4) in the first crucible may optionally be surrounded by a hollow tube (6). The hollow tube (6) may be made of steel. This hollow tube (6) is equipped with a gas inlet and a gas outlet. The gas inlet is connected to a tube which is connected to a first gas (7), this gas may be an inert gas, and a second gas (8) such as oxygen or air. The gas inlet is also connected to an oxygen content measuring device (9). This oxygen content measuring device (9) is used to know the level of oxygen in the surrounding of the material jet (5).

[0020] Material ingots are kept in both crucibles (1,2) and melted. The top part of the first crucible (1) is closed with a lid. A pressurized gas from the gas source (10) is introduced into the first crucible. The pressure thus developed forces the melt of crucible (1) to come out from the nozzle (4) as jet (5). When the nozzle (4) is opened, a material jet (5) comes out from the first crucible (1) and impinges on the surface of the second molten material (22) kept in the second crucible (2). The jet (5) entrains gas that is present in the atmosphere surrounding the

jet (5) while impinging on the surface of the molten material (22) kept in the second crucible (2). In this way bubbles are created in the second crucible (2). These bubbles rise to the surface of the melt due to buoyancy, and create foam (30) at the surface of material kept in the second crucible (2). Subsequently, the foam (30) is removed by a metallic scrapper and stored separately.

[0021] The first liquid material (20) may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of polymers. The first liquid material (20) may also be slurry of ceramics

[0022] The second liquid material (22) may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of polymers. The second liquid material (22) may also be slurry of ceramics

[0023] There are several ways to control the quality of the foam:

- a. By changing the inner diameter and length of the nozzle (4).
- b. By varying the gas pressure at the first crucible.
- c. By varying the distance between first and second crucible by moving the second crucible up and down.

d. By varying the atmosphere surrounding the material jet.

e. By varying the speed of the pump (3).

5 **[0024]** A view of an aluminum foam produced by this method and device is shown in FIG.3. X-ray tomography images of two aluminum foams are shown in FIG.4. The foam generated in this method is highly stable and therefore allows easy handling.
10 This foam can fill a hollow profile. In this way, a composite structure can be produced. A conveyer belt can be attached to the second crucible to remove the foam which is continuously being produced. In this way, this method has the potential
15 to be converted to a serial production.

[0025] This apparatus can be used for producing foams from any molten material including metals such as aluminum, zinc, magnesium, copper, iron,
20 nickel and their alloys and composites. This method and apparatus can also be used to produce foam from ceramic slurries and polymer melts.

Advantages

25 **[0026]** Unlike the existing methods to produce metal foam, this process neither needs any blowing agent nor any gas injection. Moreover, there is no need of any ceramic particles for foam stabilization.

We Claim:

1. A method of producing a material foam (30) from one or more materials comprises the steps of:
 - 5 providing a temperature controlled first crucible (1) capable of holding a first liquid material (20), the said first crucible (1) is adapted to prepare the first liquid material (20) in-situ or receiving prepared first liquid material
10 (20) from a melting source;
providing a temperature controlled second crucible (2) capable of holding a second liquid material (22), the said second crucible (2) has at least a part of its volume filled with the second
15 liquid material (22)
providing a means (3) to transfer the first liquid material (20) from the first crucible (1) to the second crucible (2) through a nozzle (4), characterized in that, on opening of the nozzle (4)
20 a jet (5) of first liquid material (20) from the first crucible (1) impinges on the second liquid material (22) in the second crucible (2) to produce a foam (30); and
scrapping the material foam (30) by a scrapper
25 and loading it to handling means.
2. The method as claimed in claim 1 wherein, the said first liquid material (20) may be melts of metals, metal alloys, metal matrix composites or their
30 combinations or melts of polymers.

3. The method as claimed in claim 1 wherein, the said second liquid material (20) may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of polymers.
- 5
4. The method as claimed in claim 1 wherein the said first liquid material (20) may be slurry of ceramics.
5. The method as claimed in claim 1 wherein the said second liquid material (20) may be slurry of ceramics.
- 10
6. The method as claimed in any of the preceding claims wherein, the said transfer means (3) may be a pump.
- 15
7. The method as claimed in any of the preceding claims wherein, the said transfer means (3) may be a means to introduce a gas (10) into the first crucible.
- 20
8. The method as claimed in any of the preceding claims may further comprise the step of controlling the atmospheric conditions surrounding the jet (5) by introducing a mixture of a first gas (7) and second gas (8).
- 25
9. The method as claimed in any of the preceding claims wherein, the said first gas (7) is any inert gas without oxygen.
- 30
10. The method as claimed in any of the preceding claims wherein, the said second gas (8) is oxygen or a mixture of air and oxygen.

11. An apparatus (25) for producing material foam comprising of:

5 a temperature controlled first crucible (1) capable of holding a first liquid material (20), the said first crucible (1) is adapted to prepare the first liquid material (20) in-situ or receiving prepared first liquid material (20) from a melting source;

10 a temperature controlled second crucible (2) capable of holding the second liquid material (22), the said second crucible (2) has at least a part of its volume filled with the second liquid material (22);

15 a means (3) to transfer the first liquid material (20) from the first crucible (1) to the second crucible (2) through a nozzle (4), characterized in that, on opening of the nozzle (4) a jet (5) of the first liquid material (20) from the first crucible (1) impinges on the second liquid material (22) in the second crucible (2) to produce foam (30); and

a means for scrapping the material foam (30) by a scrapper and loading it to handling means.

25 12. The apparatus as claimed in claim 11 wherein, the said first liquid material (20) may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of polymers.

13. The apparatus as claimed in claim 11 wherein, the said first liquid material (20) may be slurry of ceramics.
- 5 14. The apparatus as claimed in claim 11 wherein, the said second liquid material (22) may be melts of metals, metal alloys, metal matrix composites or their combinations or melts of polymers.
- 10 15. The apparatus as claimed in claim 11 wherein, the said second liquid material (22) may be slurry of ceramics.
- 15 16. The apparatus as claimed in claims 11, 12, 13, 14 or 15 wherein, the said transfer means (3) may be a pump.
- 20 17. The apparatus as claimed in claims 11, 12, 13, 14, 15 or 16 wherein, the said transfer means (3) may be a means to introduce a gas (10) into the first crucible.
- 25 18. The apparatus as claimed in claims 11, 12, 13, 14, 15, 16 or 17 may further comprise a means of controlling the atmospheric conditions surrounding the jet (5) by introducing a mixture of a first gas (7) and second gas (8).
- 30 19. The apparatus as claimed in claims 11 12, 13, 14, 15, 16, 17 or 18 wherein, the said first gas (7) is any inert gas without oxygen.

20. The apparatus as claimed in claims 11, 12, 13, 14, 15, 16, 17, 18 or 19 wherein, the said second gas (8) is oxygen or a mixture of air and oxygen.

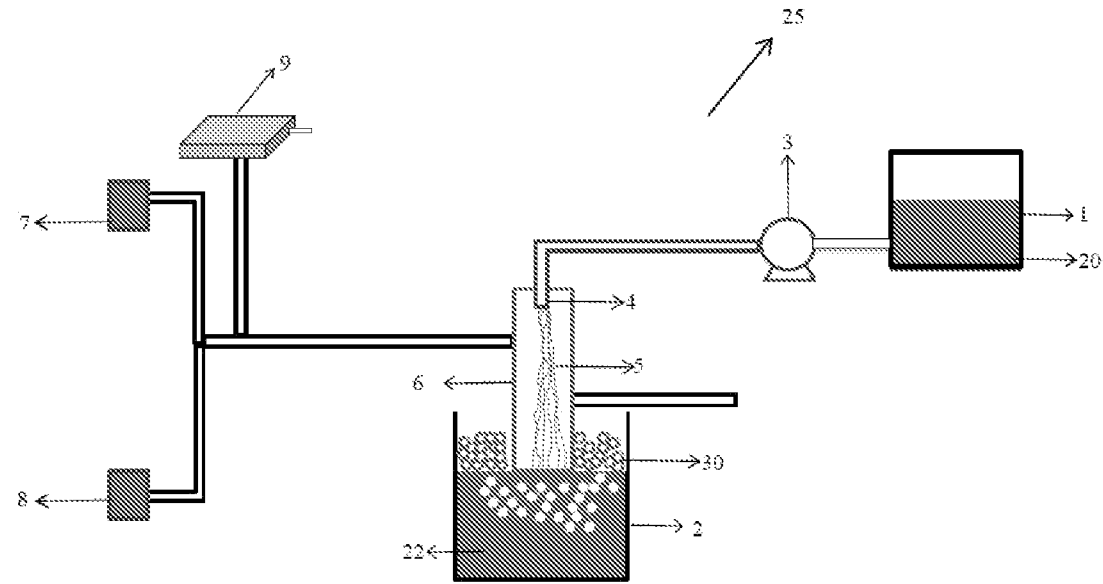


FIG.1

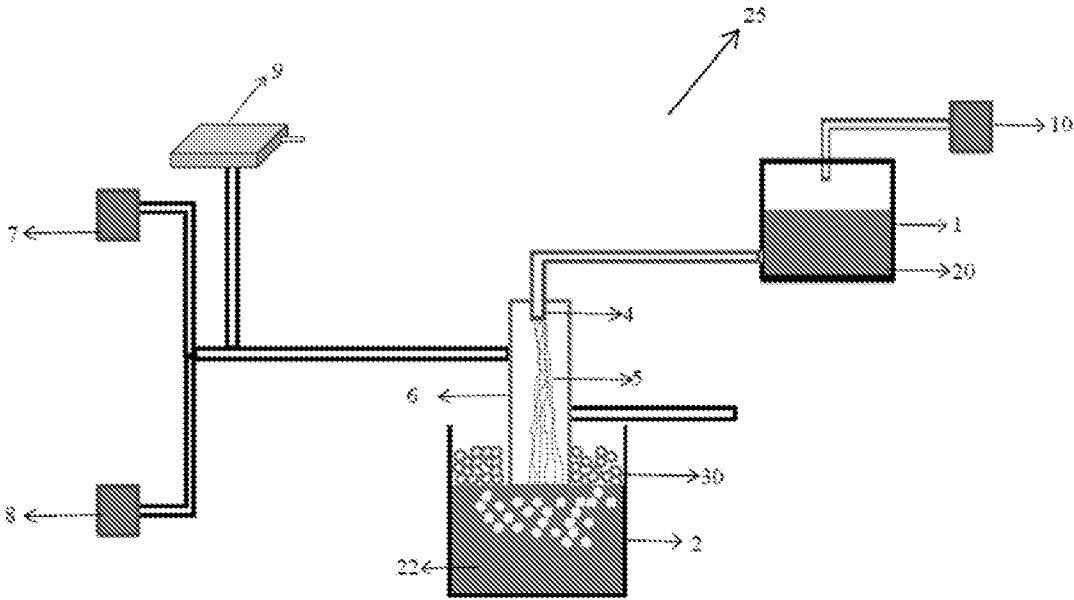


FIG.2

3/3



FIG.3

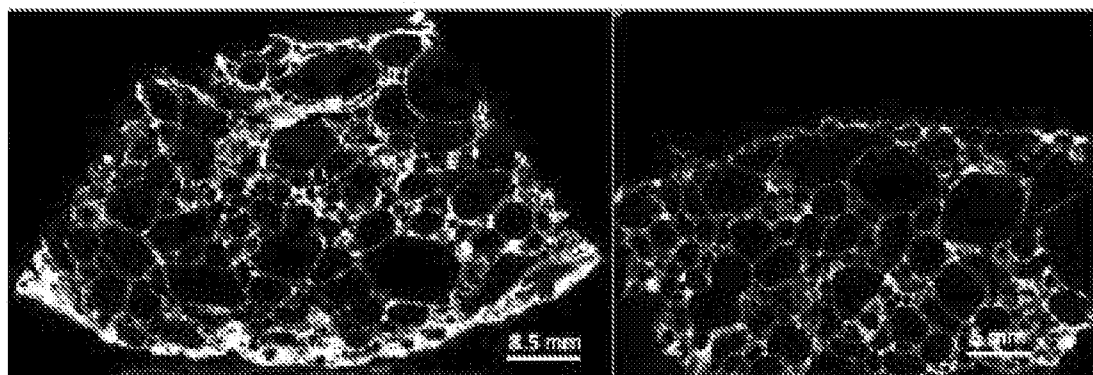


FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2018/050584

A. CLASSIFICATION OF SUBJECT MATTER
C22C1/08, B22D25/00 Version=2018.01

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)

C22C, B22D

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

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

TotalPatent One, IPO Internal Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 103695690A (HEBEI UNIVERSITY OF TECHNOLOGY) 02 April 2014 Fig 1 -3; para 3 - 21, 29 - 31; Example 1 - 2; Claim 1	1-20
A	US 5112697A (RIO TINTO ALCAN INTERNATIONAL LTD) 12 May 1992 Fig 1 - 5, Abstract, col 1 line 11 - col 2 line 66, example 1 - 3	1-20
A	DE 4139020A1 (PANTEC PANELTECHNIK GMBH) 03 June 1993 Fig 1 - 6, Abstract, para 35 - 43; claim 1 - 23	1-20

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

* Special categories of cited documents:

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"X" 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

"Y" 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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IN2018/050584

Citation	Pub.Date	Family	Pub.Date
CN 103695690 A	02-04-2014	CN 103695690 B	03-02-2016
US 5112697 A	12-05-1992	EP 0490918 A1	24-06-1992
		JP H05500391 A	28-01-1993
		CA 2066421 A1	07-03-1991
		CA 2066421 C	06-08-1996
		WO 1991003578 A1	21-03-1991
DE 4139020 A1	03-06-1993	DE 4139020 C2	24-02-1994
		CA 2084038 A1	28-05-1993
		EP 0544291 A1	02-06-1993