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(54) Title: A CAST IRON ARTICLE COMPRISING A CORROSION RESISTANT LAYER AND A METHOD OF PRODUCING SAID ARTICLE

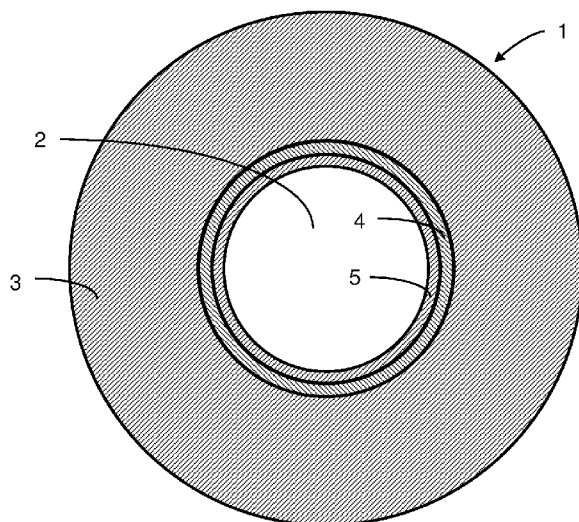


Fig. 1

(57) Abstract: An article (1) comprising a cast iron bulk material (3) and having an inner surface delimiting an internal passage (2), said inner surface being coated with a coating comprising a corrosion resistant layer (4) comprising MCrAlX, wherein M is Fe, and wherein X is an active element, and a ceramic layer (5) provided outside of the corrosion resistant layer. A method of forming such an article comprises forming a core and applying a ceramic layer and a corrosion resistant layer comprising MCrAlX, wherein M is one of Fe and Ni, and wherein X is an active element, onto the core, assembling the core into a mold, casting iron into the mold at a pouring temperature lower than the melting temperature of the corrosion resistant layer to form said article, and removing the core.

A cast iron article comprising a corrosion resistant layer and a method of producing said article

FIELD OF THE INVENTION AND PRIOR ART

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The invention relates to an article comprising a cast iron bulk material and having an inner surface delimiting an internal passage, as well as a method of producing such an article. Such articles are commonly used in e.g. exhaust system of a vehicle.

10 An example of such an article is an exhaust manifold, which has a complex geometry including internal passages. Exhaust manifolds as well as other components in exhaust systems of internal combustion engines are subjected to a corrosive environment and to elevated temperatures. However, cast iron
15 articles are sensitive to corrosion, which reduces the service life of the article and impairs the mechanical properties. Cast iron articles also show relatively high thermal conductivity. Hot exhaust gases flowing through the internal passages of an exhaust manifold made from cast iron therefore lose thermal
20 energy by heat conduction to the exhaust manifold and surrounding areas. Large thermal losses are thus present in the exhaust system, which reduce the efficiency of the engine. Moreover, the large temperature variations present in the exhaust system may lead to thermal fatigue of the exhaust
25 manifold, reducing its service life. Cast iron is however a relatively inexpensive material in comparison with more corrosion resistant alloys and it is therefore a common choice of material to keep the material costs low.

A way to partly overcome the problem with thermal losses in the exhaust system is to apply a ceramic thermal barrier coating to the outer surface of articles such as the exhaust manifold within the exhaust system. In this way, thermal conduction from the exhaust manifold to surrounding components is prevented, but the thermal conduction from the exhaust gases to the exhaust manifold itself still leads to thermal losses in the exhaust gases. Furthermore, thermal fatigue is not prevented and neither is corrosion of the exhaust manifold.

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Alternative materials such as superalloys and stainless steel are relatively expensive and are therefore not suitable for use in exhaust systems of combustion engines in vehicles such as trucks, buses, cars, etc.

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SUMMARY OF THE INVENTION

It is an object of the present invention to provide on one hand an article comprising a cast iron bulk material and having an internal passage, and on the other hand a method of producing such an article, which article and method in at least some aspect are improved with respect to known such articles and methods. In particular, it is an object to provide such an article which has improved corrosion resistance and thermal insulation properties in comparison with standard cast iron articles having an internal passage.

In the case of the article, this object is achieved by means of an article as initially defined, which is characterized in that said

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inner surface is coated with a coating comprising a corrosion resistant layer comprising MCrAlX, wherein M is one of Fe and Ni, and wherein X is an active element, and a ceramic layer provided outside of the corrosion resistant layer.

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The article according to the invention has relatively low material costs in comparison with e.g. articles having a bulk material comprising stainless steel or superalloy. However, thanks to the internal coating, it has corrosion properties which are superior to
10 plain cast iron articles and it is therefore suitable for use in corrosive environments such as in exhaust systems. The MCrAlX layer, which is preferably in the form of a distinct non-diffused layer, on one hand provides corrosion resistance and on the other hand forms an excellent bond layer for bonding the ceramic
15 layer to the article. The ceramic layer is preferably a so called thermal barrier coating, providing good thermal insulation properties. The article according to the invention is therefore suitable for use in e.g. exhaust systems of combustion engines, in which exhaust gases of elevated temperature flows through
20 the internal passage of the article. The ceramic coating prevents thermal conduction from the exhaust gases to the bulk material of the article. It therefore efficiently minimizes power losses in the exhaust system and thereby increases the efficiency of the engine. It also increases the corrosion resistance of the bulk
25 material, since corrosion is generally promoted at high temperatures. Thereby, also the mechanical properties of the article are improved with respect to plain cast iron articles.

According to the invention, the corrosion resistant layer
30 comprises FeCrAlX. By using FeCrAlX, both the corrosion

resistant layer and the bulk material are ferritic, which means that the thermal expansion properties of the bulk material and the corrosion resistant layer are essentially the same. The stability of the coating during thermal cycling is thereby increased.

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According to the invention, the corrosion resistant layer comprises between 8–15 % Cr by weight, preferably between 10–14 % Cr by weight. By keeping the chromium content of the corrosion resistant layer relatively low, the risk of forming chromium carbides in the interface between the cast iron bulk material and the corrosion resistant layer is reduced. This is thus an alternative way to prevent the bulk material from embrittlement and to improve the adhesion of the corrosion resistant layer. Of course, an alumina layer may additionally be formed between the bulk material and the corrosion resistant layer to further reduce the risk of forming chromium carbides.

According to an embodiment of the invention, the corrosion resistant layer has a thickness in the range 0.05–1 mm, preferably 0.05–0.5 mm, and more preferably 0.1–0.5 mm. This thickness is sufficient to provide corrosion resistance to the article and the layer is also thin enough to keep the material costs low.

According to an embodiment of the invention, the ceramic layer has a thickness in the range 0.05–1 mm, preferably 0.2–0.5 mm. With a ceramic layer of this thickness, sufficient thermal insulation properties are achieved while the material costs are kept reasonable. A too thick layer may lead to spallation while a too thin layer gives insufficient thermal insulation properties.

According to an embodiment of the invention, the ceramic layer comprises one of a stabilized zirconium oxide, mullite, or forsterite. These materials are all known to have suitable thermal insulation properties.

According to an embodiment of the invention, the ceramic layer comprises yttria-stabilized zirconia. In this embodiment, the ceramic layer has excellent thermal insulation properties.

According to an embodiment of the invention, the coating further comprises an alumina layer formed between the corrosion resistant layer and the cast iron bulk material. The alumina layer reduces the risk of forming chromium carbides in the interface between the cast iron bulk material and the corrosion resistant layer due to carbon diffusion. Chromium carbides may otherwise embrittle the corrosion resistant layer material close to the bulk material and thereby reduce the adhesion of the layer. In this embodiment, the alumina layer protects the corrosion resistant layer material from embrittlement and the adhesion of the corrosion resistant layer is improved.

According to an embodiment of the invention, the alumina layer has a thickness of less than 500 nm, preferably less than 200 nm. An alumina layer of this thickness is sufficient to form an efficient barrier for carbon diffusion.

According to an embodiment of the invention, the article is an exhaust manifold. Advantages and advantageous features of such an exhaust manifold are as listed above.

According to a second aspect of the invention, the above mentioned object is achieved by means of a method of producing an article comprising a cast iron bulk material and having an inner surface delimiting an internal passage, comprising the

5 forming a core for defining the internal passage,

applying a ceramic layer onto the core,

applying a corrosion resistant layer comprising MCrAlX onto the ceramic layer, wherein M is one of Fe and Ni, and wherein X is

10 an active element,

assembling the core into a mold,

casting iron into the mold to form said article, and

removing the core.

15 The corrosion resistant layer has a much higher melting temperature than the cast iron bulk material, typically about 1500°C as compared to a pouring temperature of 1350°C, and MCrAlX therefore forms a distinct and non-diffused layer on the inner surface of the bulk material. By means of the inventive

20 method, cast iron articles of complicated geometry can be formed with a thermally insulating and corrosion resistant coating on an internal surface of the article. The corrosion resistant layer, apart from protecting against corrosion, forms an excellent bond layer for bonding the ceramic layer onto the article. Therefore, the

25 application of a corrosion resistant layer is crucial for the quality of the ceramic layer and is a prerequisite for obtaining the thermally insulating properties offered by the ceramic layer. Without the corrosion resistant MCrAlX layer, the adhesion of the ceramic layer to the cast iron bulk material will be too poor.

According to an embodiment of this aspect of the invention, the method further comprises the step:

oxidizing the corrosion resistant layer before casting iron into the mold, such that an alumina layer is formed between the corrosion resistant layer and the cast iron bulk material. In this way, the risk of forming chromium carbides in the interface between the cast iron bulk material and the corrosion resistant layer is reduced. Thereby, the bulk material is protected from embrittlement and the adhesion of the corrosion resistant layer is improved.

According to an embodiment of this aspect of the invention, thermal spraying is used in the step of applying a ceramic layer. Thermal spraying includes e.g. plasma spraying, flame spraying, wire arc spraying, etc. Thermal spraying is an efficient way of applying a coating in the form of a ceramic layer of a desired thickness on the core, which may be e.g. a sand core or the like.

According to an embodiment of this aspect of the invention, thermal spraying is used in the step of applying a corrosion resistant layer. This is an efficient way of applying a coating in the form of a corrosion resistant layer of a desired thickness on top of the ceramic layer.

Other advantageous features as well as advantages of the present invention will appear from the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will in the following be further described by means of example with reference to the appended drawings, wherein

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Fig. 1 schematically shows a cross section of an article according to the invention,

Fig. 2 schematically shows a partial cross section of an article according to the invention, and

10 Fig. 3 shows a flow chart of a method according to the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE
15 INVENTION

An article 1 according to a first embodiment of the invention is schematically shown in cross section in fig. 1. The article 1 is formed with an internal passage 2 and comprises a cast iron bulk
20 material 3, a corrosion resistant layer 4 applied on the cast iron bulk material 3 on its side facing the internal passage 2, and a ceramic layer 5 applied on the corrosion resistant layer 4. In the shown embodiment, the corrosion resistant layer 4 is preferably in the form of a ferritic FeCrAlX layer, wherein X is one or more
25 of Hf, Y, Ti, Zr, La, Th, Ce, or one or more other reactive elements known in the art. The FeCrAlX corrosion resistant layer 4 on one hand prevents corrosion of the cast iron bulk material 3 and on one hand increases the adhesion of the ceramic layer 5. The corrosion resistant layer 4 preferably has a thickness in the
30 range 0.05–1 mm, preferably 0.05–0.5 mm, and more preferably

0.1–0.5 mm. Since the FeCrAlX corrosion resistant layer 4 is in direct contact with the cast iron bulk material 3, it is preferable to use a FeCrAlX comprising between 8–15 % Cr by weight, preferably between 10–14 % Cr by weight. Typically, the FeCrAlX layer may comprise about 10 % Cr by weight. With this relatively low chromium content, the risk of forming chromium carbides in the interface between the corrosion resistant layer 4 and the cast iron bulk material 3 is reduced, and thereby also the risk of embrittlement of the corrosion resistant layer 4. The ceramic layer 5 has approximately the same thickness as the corrosion resistant layer 4 and is a thermal barrier layer in the form of e.g. a stabilized zirconium oxide, preferably yttria-stabilized zirconia, mullite, or forsterite.

A partial cross section of an article 1 according to a second embodiment is schematically shown in fig. 2. In this embodiment, the article 1 comprises a cast iron bulk material 3, a corrosion resistant layer 4 in the form of a FeCrAlX layer, wherein X is chosen according to above, and a ceramic layer 5 applied on the corrosion resistant layer 4. The article 1 in this second embodiment differs from the article 1 according to the first embodiment in that between the corrosion resistant layer 4 and the cast iron bulk material 3, a thin alumina layer 6 is formed. The alumina layer 6 acts as a barrier layer against carbon diffusion into the FeCrAlX layer 4 and thereby prevents embrittlement of the FeCrAlX layer 4 close to the bulk material 3. Thus, in this embodiment, the chromium content in the corrosion resistant FeCrAlX layer 4 may be increased to around 20–22 % by weight, which improves the corrosion resistance of the article

1. The alumina layer 6 has a thickness of less than 500 nm, preferably less than 200 nm.

In a method according to the invention, an article 1 is formed by means of a casting process. The method is schematically illustrated as a flow chart in fig. 3. In a first step S1, a core for defining an internal passage 2 in the article 1 is formed. The core can be e.g. a resin bonded sand core or similar. In a step S2, a ceramic layer 5, preferably in the form of an yttria-stabilized zirconia layer, is applied onto the core, e.g. by thermal spraying using any of plasma spraying, flame spraying, wire arc spraying, etc. After applying the ceramic layer 5, a corrosion resistant layer 4 comprising e.g. FeCrAlX, wherein X is one or more of Hf, Y, Ti, Zr, La, Th, Ce, or one or more other reactive elements known in the art, is applied by thermal spraying in a step S3. In an optional step S4, the corrosion resistant layer 4 is subjected to an oxidization, whereby a thin alumina layer 6 is formed on top of the corrosion resistant FeCrAlX layer 4. Thereafter, the core is assembled into a mold in a step S5, and iron is cast into the mold at a pouring temperature of approximately 1350°C in a step S6 to form the article 1. The pouring temperature is lower than the melting temperature of the corrosion resistant layer 4, which for FeCrAlX is typically around 1500°C, so the corrosion resistant layer 4 thereby forms a non-diffused distinct layer on the cast iron bulk material 3. In a step S7, the core is removed and the internal passage 2 is formed. The article 1 formed according to the method comprises a cast iron bulk material 3, and on its inner surface a coating comprising a thin alumina layer 6, a corrosion resistant layer 4 and a ceramic layer 5 is formed.

In a cast iron exhaust manifold according to the invention, the internal passages in which exhaust gases flow are covered with a ceramic layer acting as a thermal barrier between the exhaust gases and the bulk material, a corrosion resistant layer bonding
5 the ceramic layer to the bulk material and preventing corrosion of the bulk material, and optionally an alumina layer preventing formation of chromium carbides in the corrosion resistant layer.

The invention is of course not in any way restricted to the embodiments described above, but many possibilities to modifications thereof would be apparent to a person with skill in the art
10 without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. An article (1) comprising a cast iron bulk material (3) and having an inner surface delimiting an internal passage (2),
5 wherein said inner surface is coated with a coating comprising:
a corrosion resistant layer (4) comprising MCrAlX, wherein M is one of Fe and Ni, and wherein X is an active element, and
a ceramic layer (5) provided outside of the corrosion resistant layer (4),
10 **characterized in**
that the corrosion resistant layer (4) comprises FeCrAlX, and that the corrosion resistant layer (4) comprises between 8–15 % Cr by weight.
- 15 2. The article according to claim 1, wherein the corrosion resistant layer (4) has a thickness in the range 0.05–1 mm, preferably 0.05–0.5 mm, and more preferably 0.1–0.5 mm.
3. The article according to claim 1 or 2, wherein the ceramic
20 layer (5) has a thickness in the range 0.05–1 mm, preferably 0.2–0.5 mm.
4. The article according to any of the preceding claims, wherein the ceramic layer (5) comprises one of a stabilized
25 zirconium oxide, mullite, or forsterite.
5. The article according to claim 4, wherein the ceramic layer (5) comprises yttria-stabilized zirconia.
- 30 6. The article according to any of the preceding claims, wherein the coating further comprises an alumina layer (6)

formed between the corrosion resistant layer (4) and the cast iron bulk material (3).

7. The article according to claim 6, wherein the alumina layer
5 (6) has a thickness of less than 500 nm, preferably less than 200 nm.

8. The article according to any of the preceding claims,
wherein the corrosion resistant layer (4) comprises between 10–
10 14 % Cr by weight.

9. An article according to any of the preceding claims, wherein the article is an exhaust manifold.

15 10. A method of producing an article (1) comprising a cast iron bulk material (3) and having an inner surface delimiting an internal passage (2), comprising the steps:

forming a core for defining the internal passage (2),

applying a ceramic layer (5) onto the core,

20 applying a corrosion resistant layer (4) comprising MCrAlX onto the ceramic layer (5), wherein M is one of Fe and Ni, and wherein X is an active element,

assembling the core into a mold,

25 casting iron into the mold at a pouring temperature lower than the melting temperature of the corrosion resistant layer (4) to form said article (1), and

removing the core.

30 11. The method according to claim 10, further comprising the step:

oxidizing the corrosion resistant layer (4) before casting iron into the mold, such that an alumina layer (6) is formed between the corrosion resistant layer (4) and the cast iron bulk material (3).

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12. The method according to any of the claims 10–11, wherein thermal spraying is used in the step of applying a ceramic layer (5).

10 13. The method according to any of the claims 10–12, wherein thermal spraying is used in the step of applying a corrosion resistant layer (4).

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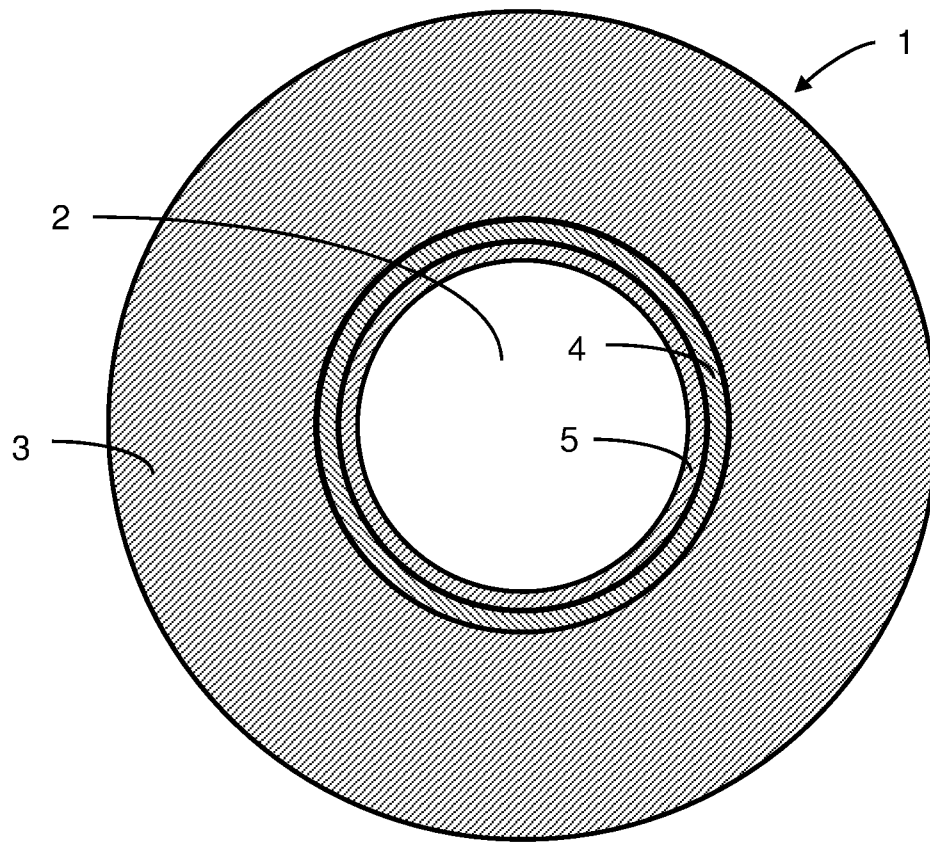


Fig. 1

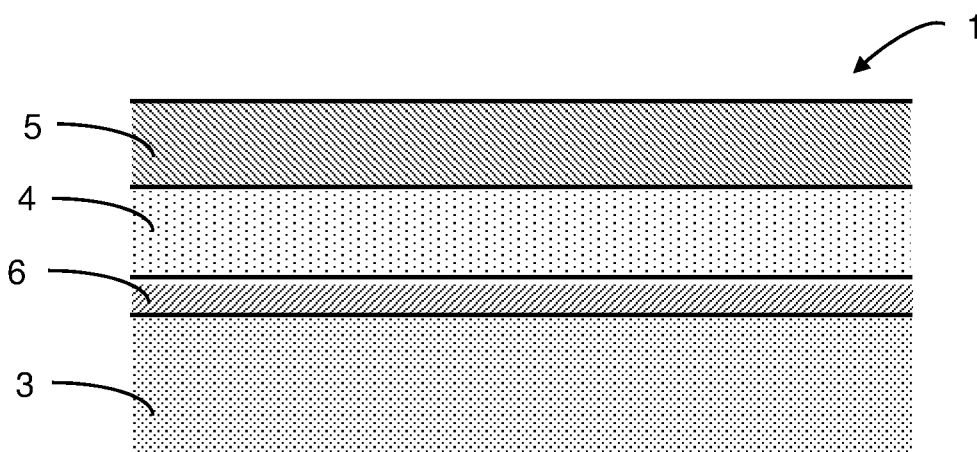
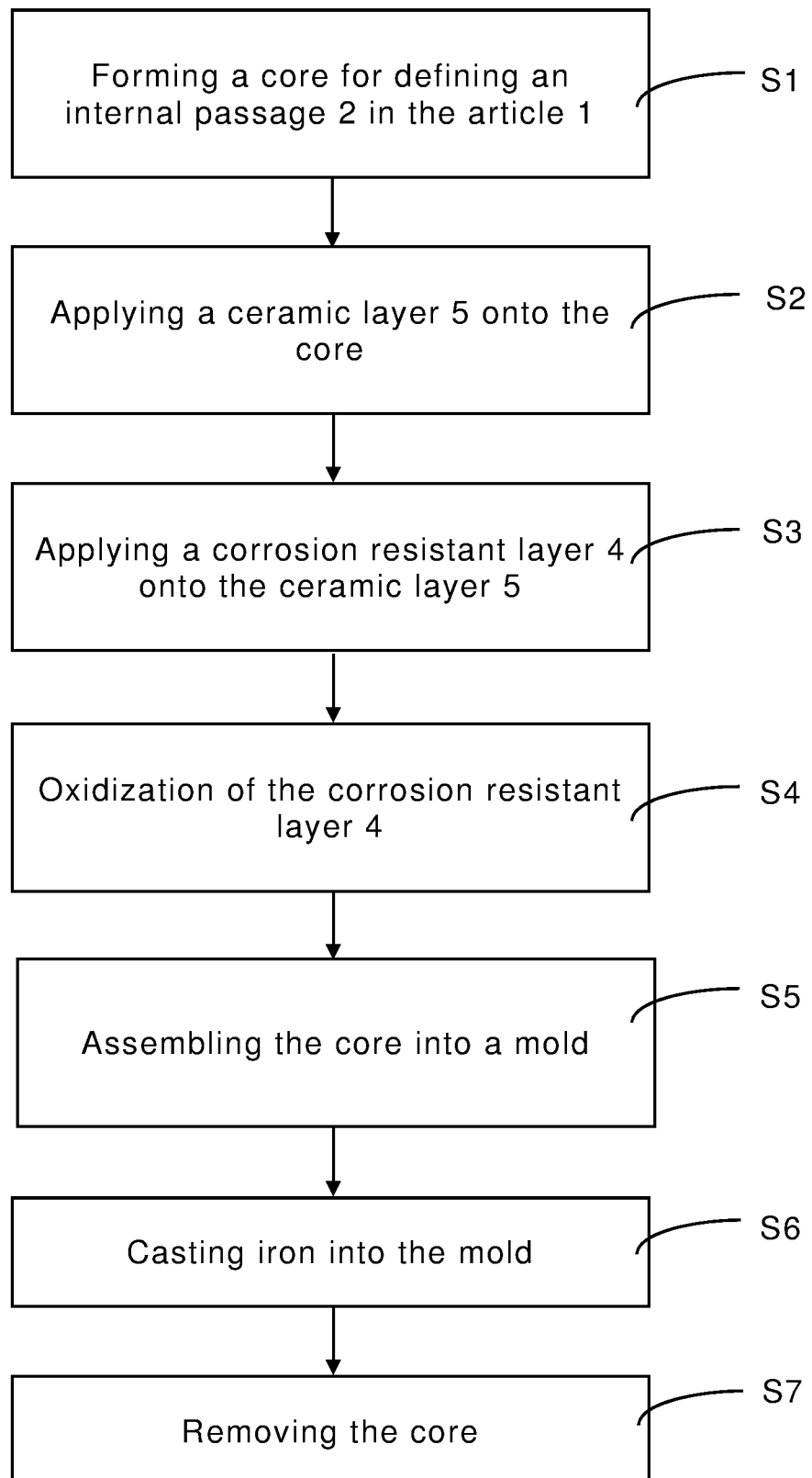


Fig. 2

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2015/051108

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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: C23C

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5384200 A (GILES DAVID C ET AL), 24 January 1995 (1995-01-24); abstract; column 3, line 62 - column 3, line 64; column 4, line 13 - column 4, line 35; column 5, line 32 - column 5, line 36; figure 2 --	1-13
A	US 4495907 A (KAMO ROY), 29 January 1985 (1985-01-29); abstract; column 1, line 13 - column 1, line 17; column 2, line 18 - column 2, line 22; column 2, line 44 - column 2, line 68 --	1-13
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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“E” earlier application or patent but published on or after the international filing date

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“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” 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

“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

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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.
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Continuation of: second sheet

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C23C 6/00 (2006.01)

C23C 30/00 (2006.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

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