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(54) **ANODE ASSEMBLY FOR CORROSION CONTROL OF STEEL REINFORCED CONCRETE STRUCTURES**

ANODENANORDNUNG ZUR KORROSIONSKONTROLLE VON STAHLVERSTÄRKTEN BETONSTRUKTUREN

ENSEMBLE ANODE POUR LA LUTTE CONTRE LA CORROSION DE STRUCTURES EN BÉTON ARMÉ D'ACIER

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## Description

### FIELD OF THE INVENTION

**[0001]** This invention relates to a sacrificial anode assembly for corrosion control.

**[0002]** More specifically, to a sacrificial anode assembly for corrosion control of reinforcing steel embedded in concrete and the like.

### BACKGROUND OF THE INVENTION

**[0003]** Cathodic protection systems for corrosion control of reinforcing steel embedded in concrete are known in the art. US2014/027306 for instance describes that corrosion of steel in a concrete structure such as a column in sea water occurs primarily above the water line and is inhibited using cathodic protection by attaching to the column an impervious sealed sleeve in which is provided a sacrificial anode in sheet form in contact with a layer of water transport medium so that water from the location of the bottom of the water transport medium within the water is carried into the area of the sacrificial anode to enhance ionic current. US2013015058 describes a galvanic panel that has a compliant compressible material layer held on a backing by an adhesive or mortar thinner than a galvanic mortar layer and said galvanic mortar layer contains a sacrificial galvanic anode material and is applied over the compliant compressible material layer.

### SUMMARY OF THE INVENTION

**[0004]** Cathodic protection (CP) of reinforcing steel has been applied to reinforced concrete structures with corrosion damage for over 30 years. Worldwide experience shows that CP prevents further damage in a reliable and economical way for an extensive period of time. CP is particularly suited in cases where chloride contamination is the leading cause of corrosion. The first applications started on bridge decks suffering from corrosion due to de-icing salt penetration which resulted in severe damage to the concrete. Since the 1970's, CP has been applied worldwide to buildings, marine structures, tunnels, bridge decks and substructures.

**[0005]** The normal condition of steel reinforcement in concrete is passivity. This is a state with an almost negligible corrosion rate, thanks to a thin iron hydroxide complex comprising film (passive layer) on the steel surface, which is stabilized by the inherently high pH of approximately 13 in concrete. Basically, this passive layer on reinforcement steel in concrete may be lost by two mechanisms: either carbon dioxide ingress, which reduces the pH to a level of approx. 9 (carbonation), causing an essentially uniform loss of passivation, or the presence of chloride ions, which locally break down the passive film, thus initiating pitting corrosion. Chloride may be either be mixed in the concrete or may penetrate the concrete from the environment.

**[0006]** The type of corrosion that occurs in reinforced concrete is an electrochemical phenomenon, in which the electrochemical potentials of (micro and macro corrosion cells in) the reinforcing steel and the exchange of electrical current between the steel and the surrounding electrolyte, liquid that is present in the pores of the concrete, play important roles. In the passive state, the potential of the steel is relatively positive, due to chemical reaction between oxygen and the steel surface. When passivity is lost, iron passes into solution in the form of ferrous ions, leaving an excess of electrons in the steel, which makes the potential of these spots more negative; this reaction is termed 'anodic'. Potential differences between anodic sites and the remaining, passive, surface of the steel, the so-called cathodic areas, cause electric currents in the steel reinforcement and ionic currents in the liquid inside the concrete pores to flow, thereby accelerating the steel dissolution reaction. The corrosion products are significantly more voluminous than the original steel. The net effect is expansion of the reinforcement, causing tensile stresses in the surrounding concrete. After relatively small amounts of steel have been transformed into corrosion products, the concrete cover may crack and spalling or delamination occurs. Cracking and spalling in themselves can be unacceptable, but they also have to be taken as a warning sign of further structural decay. When left unattended to corrode, the steel bar diameter may be reduced to values below structurally acceptable limits. Eventually this can lead to the collapse of a concrete structure. Therefore, concrete repair may be necessary, and the corrosion protection must be reinstated, for example by cathodic protection.

**[0007]** Cathodic protection of reinforcing bars in concrete is based on changing the potential of the steel to more negative values in order to reduce potential differences between anodic and cathodic sites and hence reducing the corrosion current to negligible values. The change of potential is called polarization. In practice, this can be achieved in two ways, either by means of sacrificial anodes or by means of impressed current.

**[0008]** A sacrificial anode cathodic protection assembly is effectuated by mounting an electrode, the anode, on the concrete surface or by embedding it in the concrete and connecting it to the reinforcement steel cage. Through the steel reinforcement cage, electrons flow to the steel/concrete interface, increasing the so-called cathodic reactions, which produce hydroxide ions from oxygen and water. On the other hand sacrificial anode ions are formed at the anode/electrolyte interface and migrate through the electrolyte where they can be oxidized to any metal-complex and electrons. The basic electrochemical reaction at the anode of a sacrificial anode cathodic protection assembly in reinforced concrete is :

$$Me \longrightarrow Me^{n+} + n\,e^{-}$$

**[0009]** The electrons flow to the current source, which closes the electrical circuit. Essentially, the electrical circuit is based on a plurality of (serial) redox reactions at an interfacial (or contact) surface of an electrode and an electrolyte combined with a transport of the electrons, wherein in one of the redox reactions an electron is formed and in another one an electron is consumed. The electrons may be transported directly via electrical conduction, such as via an electrically conductive material that may be provided between the sacrificial anode and the cathode (the reinforcement steel). To close the circuit, the electrodes may further be transported indirectly via a transport of ions via an electrolyte/electrolytic material or ion-conductive material arranged between the cathode and the anode. As a result of this current circulation, cathodic reactions are favored and anodic reactions at the steel surface are suppressed. Even relatively moderate current densities are able to restore passivity of the reinforcing steel and have various beneficial chemical effects.

**[0010]** The term "sacrificial anode" may also be known as a "galvanic anode". Moreover, "sacrificial anode cathodic protection" is also known as "galvanic cathodic protection" ("galvanic CP") or sometimes also called "passive cathodic protection" ("passive CP"). The term "galvanic" may especially be used because a galvanic cell is formed when the cathode (and the anode) is exposed to the electrolyte (the concrete - or better, the water in the concrete - in the above given explanation). The galvanic system as formed by the anode, cathode and concrete is a "constant potential" system that aims to restore the concrete's natural protective environment especially by providing a high initial current based on a high potential difference between the anode and the reinforcement steel, thereby restoring passivity and generation of hydroxide ions at the steel surface. The generated hydroxide ions migrate away from the steel and towards the anode and may restore the concrete environment. As a result of the high initial current, the potential of the steel may become more negative, and the current may become lower. The sacrificial current may further induce a migration of harmful negative chloride ions through the electrolyte away from the steel and towards the positive anode. The galvanic anode remains reactive through its lifetime, increasing current when the resistivity decreases due to corrosion exposures, for instance caused by rainfall, salt attacks and temperature rise.

**[0011]** Probably the most important limitation of present sacrificial anode based CP systems for the protection of reinforcement in concrete is the limitation in the throwing power of discrete sacrificial anodes. The term throwing power refers to the distance of the electric field established inside the concrete, which is a material with a high resistivity.

**[0012]** Hence, it is an aspect of the invention to provide an alternative anode assembly for sacrificial anode based cathodic protection, which preferably further at least partly obviates one or more of above-described drawbacks. It is a further aspect to provide a method to protect (metal) reinforcement material in reinforced concrete, which preferably further at least partly obviates one or more of above-described drawbacks. In yet a further aspect, the invention provides a concrete comprising object comprising the assembly for cathodic protection. The present invention may have as object to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

**[0013]** Hence, in a first aspect, the invention provides an anode assembly for sacrificial anode based cathodic protection (or "galvanic cathodic protection") of (reinforcement material, especially steel, in) (steel) reinforced concrete, according to claim 1. The anode assembly comprises an electrically conductive (coating) layer ("layer" or "coating layer") for providing at (or provided to/at) a surface of the reinforced concrete (to be protected), especially for (directly/physically) (electrolytically) contacting the reinforced concrete. Further, the assembly comprises an electrolytic material ("electrolyte" or "ion-conductive material") (electrolytically (and physically)) connected to the electrically conductive layer. In embodiments, the conductive (coating) layer is configured for (electrolytically (and physically)) contacting the surface of the reinforced concrete at a first side of the (electrically) conductive (coating) layer, and the electrolytic material is arranged at another side ("outer side" or facing away from the conductive layer) of the conductive layer (especially directly) (electrolytically) contacting the conductive (coating) layer). The anode assembly comprises a sacrificial anode (electrolytically and physically) connected to the electrolytic material. In further specific embodiments, the electrolytic material is at least partly sandwiched between the sacrificial anode and the conductive (coating) layer. The sacrificial anode may in embodiments indirectly (physically and electrically) be connected to the conductive (coating) layer via the electrolytic material. The electrolytic material electrolytically connects the sacrificial anode to the conductive (coating) layer.

**[0014]** Such anode assembly may be able to distribute the (electric) current over an expanded surface area of the concrete. The anode assembly may be able to reduce the effect of the concrete's high electrical resistance which in prior art systems restrict the sacrificial anode's throwing power. Especially, a (total) number of anode assemblies to protect a determined amount of concrete may be lower than the number of prior art anode assemblies required to protect the same amount of concrete. Moreover, where in prior art anode assemblies a (total) contact (interfacial) surface area between the anode and the concrete may determine the throwing power, in the anode assembly of the invention a (total) contact surface area between the conductive layer and the concrete may determine the throwing power.

**[0015]** Hence, in embodiments, the invention provides an anode assembly for sacrificial anode based cathodic protection of reinforced concrete, wherein the anode assembly comprises an electrically conductive layer for providing at (to) (and electrolytically connecting with) a surface of the reinforced concrete to be protected and an electrolytic material (electrolytically) connected to the electrically conductive layer (especially at a side of the conductive layer remote from the reinforced concrete).

**[0016]** The anode assembly comprises a sacrificial anode electrolytically connected to the electrolytic material. The sacrificial anode especially not directly (electrically) contacts the (conductive) layer. The electrolytic material electrolytically connects the sacrificial anode to the electrically conductive layer. In further specific embodiments, the sacrificial anode (electrolytically) contacts the electrolytic material at a first location (of the electrolytic material), such as at a first side of the electrolytic material, and the electrically conductive layer (electrolytically) contacts the electrolyte at a second location (of the electrolytic material) (different from the first location), such as at another side of the electrolytic material.

**[0017]** In further embodiments, the invention comprises a sacrificial anode assembly of a cathodic protection system for reinforced concrete structures using electrode materials such as for example zinc, aluminium, magnesium, or any alloy thereof in any form or shape, embedded in, covered by or coated with an electrolyte that keeps the electrode material active, wherein the electrolyte is in direct contact with an electrically conductive material comprising for example a coating, mortar or metallized film or any other material which can be applied on concrete with the purpose of distributing the current coming from the anode over an expanded surface area of the concrete.

**[0018]** The electrically conductive layer may essentially comprise any arbitrarily material that is able to conduct electrons. The electrically conductive layer may, e.g., comprise a conductive coating. The electrically conductive layer may in embodiments comprise a mortar or for instance a metallized layer. The electrically conductive layer especially comprises an electrically conductive material that in embodiments can be applied on a (concrete) surface through spraying, such as through cold spraying or thermal spraying. In further specific embodiments, the electrically conductive layer comprises a thermally sprayed coating, especially comprising a film, coating and/or layer. The electrically conductive layer may in embodiments comprise expanded metal (sheet) or a metal mesh. The electrically conductive layer may comprise a film or a coating. In further embodiments, the electrically conductive layer comprises a (metal) strip. The electrically conductive layer may further comprise an electrically conductive mortar. The electrically conductive layer may in embodiments comprise a metalized (or metal) layer. The electrically conductive layer especially comprises a layer of electrically conductive material.

**[0019]** A thickness of the electrically conductive layer may in embodiments be equal to less than 5 mm, such as equal to or less than 2 mm, even more especially equal to or less than 1 mm. In embodiments, the thickness of the coating is at least 50 μm, especially at least 100 μm, even more especially at least 200 μm. In embodiments the thickness of the conductive layer is in the range of 100-2000 μm, especially 200-1000 μm, such as 250-500 μm. Said thickness is in embodiments in the range of 100-5000 μm, especially 100-1000 μm, such as 100-500 μm. Yet, also thicker conductive layers are possible. Increasing the thickness may advantageously reduce the electrical resistance, however, will increase the cost. The term thickness may in embodiments, especially wherein the conductive layer is configured for covering the concrete surface as a film, or a continuous layer relate to a mean thickness. Yet, in further embodiments, e.g. comprising a mesh or expanded metal, the term may relate to a maximal thickness (of the e.g. of wires of the mesh, or the metal in the expanded metal layer).

**[0020]** The term "metallized film" or "metallized layer" used herein may especially relate to a film or coating comprising metal material. The film or layer may in embodiments be provided using thermal spraying. The metal in the metallized film may thus especially be selected for being electrically conductive and allowing it to be thermally sprayed. The metallized film may e.g. comprise a thermal sprayed zinc layer, a thermal sprayed aluminium layer, a thermal sprayed titanium layer, etc. In further embodiments, the electrically conductive layer comprises metal particulate materials. Additionally or alternatively, the electrically conductive layer comprises a conductive polymer (particulate material) and/or graphite (particulate material).

**[0021]** The assembly further especially comprises the electrolytic material or electrolyte. The electrolytic material (ion-conductive material) is especially selected for being conductive to ions. Some examples of such materials are polyvinylpyrrolidone ("PVP") and polyvinyl alcohol ("PVA") based hydrogels or combinations of it, inorganic or polymeric based ion gels ("ionogels" or "iongels"), water-based adhesives, and solid electrolytes or semi-solid electrolytes used for batteries.

**[0022]** Hence, in embodiments, the electrolytic material comprises a PVP based hydrogel and/or a PVA based hydrogel. In further embodiments, the electrolytic material comprises an ion gel. Additionally or alternatively, the electrolytic material comprises water-based adhesives. In yet further embodiments, the electrolytic material comprises (or consists of), a solid electrolyte (and/) or a semi-solid electrolyte used for batteries, e.g. comprising lithium. Moreover, in embodiments the electrolytic material may comprise combinations of the above given electrolytes (electrolytic materials).

**[0023]** The electrolytic material may essentially form a layer between the anode and the conductive layer. A thickness (or dimension) of the electrolytic material (layer) may in embodiments be at least 100 μm, especially at least 500 μm, such as at least 750 μm, especially at least 1000 μm. In embodiments the thickness is about 1 mm. In further embodiments, the thickness is at least 2 mm, or at least 4 mm. The thickness of the electrolyte material is especially less than 5 mm, such as equal to or less than 2 mm. In embodiments, the thickness may be higher than 5 mm. The thickness of the electrolytic material especially refers to a minimal distance between the anode and the conductive layer. If the thickness is very low, the anode may directly contact the conductive layer (because of irregularities) resulting in short circuit. Furthermore, the electrolyte material may also require a minimum volume (and thus thickness) to accumulate possible complexes that are formed in the material.

**[0024]** Polyvinylpyrrolidone (PVP) is a water-soluble polymer made from the monomer N-vinylpyrrolidone and is also commonly named polyvidone or povidone. An ion gel is a composite material consisting of an ionic liquid immobilized by an inorganic or a polymer matrix. The ion gel may have a high ionic conductivity while in the solid state. To create an ion gel, e.g., the solid matrix is mixed or synthesized in-situ with an ionic liquid. For instance a block copolymer which is polymerized in solution with an ionic liquid may be used to generate a self-assembled nanostructure where the ions are selectively soluble. Ion gels may further, e.g., be made using non-copolymer polymers such as cellulose, oxides such as silicon dioxide or refractory materials such as boron nitride.

**[0025]** The electrolytic material is especially a solid material, a semi-solid material or a highly viscous material. The material is especially not mobile (flowable). Yet especially, during use ions may be mobile in the electrolytic material (and the electrolytic material is stagnant/immobile). In further embodiments, the electrolytic material comprises an adhesive material or is part of an adhesive material. The electrolytic material may comprise an adhesive ion-conducting material. In such embodiments, the anode may be bond to the electrically conductive layer by means of the electrolytic material. In further embodiments, the anode and the electrolytic material may be pre-assembled. The pre-assembled anode/electrolytic material combination (or sub assembly) may be provided to the electrically conductive coating to provide embodiments of the anode assembly. In specific embodiments, the adhesive electrolytic material is bond to the anode forming the pre-assembled sub assembly (arrangement) (or pre-assembled assembly). The adhesive electrolytic material may especially be covered with a film or sheet to cover the adhesive electrolytic material before use. The pre-assembled (sub) assembly may than be bond to the electrically conductive layer after removing the film. Such pre-assembled assembly may in embodiments be advantageously arranged at the concrete. The pre-assembled (sub) assembly may be replaced by a new pre-assembled (sub) assembly when the sacrificial anode is significantly consumed. Hence, in embodiments, the sacrificial anode and the electrolytic material applied in the anode assembly comprise (or define) a pre-assembled (sub) assembly.

**[0026]** The minimal distance between the anode and the conductive layer may in embodiments have a value as described in relation to the thickness of the electrolytic material.

**[0027]** Herein the terms "ion-conductive material" and "electrolytic material" may be used interchangeably. The terms may refer to an "(anode activating) electrolyte". Herein further the terms "electrolytical(ly) contact" (or connection), and "electric(ally) connection (contact)" and the like are used. These terms especially relate to a (direct) physical contact/connection. Further, an electrolytic connection relates to allowing ions to cross the interface between the elements that are electrolytically in contact with each other; whereas an electrical connection relates to allowing electrons to cross the interface between the elements that are electrically in contact with each other.

**[0028]** At the core of any sacrificial anode assembly for cathodic protection is the anode or electrode material. Such materials are available on the market in various types, forms and shapes. Depending on the application, the anodes comprise metals such as zinc, aluminium, magnesium or any alloy based on one or more of these metals. Basically, the anode may comprise any material having a lower (that is, more negative) electrode potential than that of the cathode (especially the reinforcement steel). Common sacrificial anode materials for cathodic protection systems for reinforced concrete structures comprise for example:

- zinc, or any alloy thereof, especially in the form of wire mesh, wire, strip, tape, or tubes, shaped to fit the surface of the structure and to subsequently be covered with a cementitious overlay, such as for example spray crete or shotcrete;
- or wires, strips, mesh or tubes placed in holes, openings, or slots in the concrete and backfilled with cementitious grouts;
- thermally sprayed coatings or otherwise applied coatings covering the concrete surface.

**[0029]** The sacrificial anode of the invention may comprise any arbitrary form or shape. In embodiments, the sacrificial anode comprises a shape or form described above. In embodiments, the anode for instance may comprise a disk, a bar, a block or a strip. Moreover, in further embodiments, the sacrificial anode may comprise a material described herein in relation to known (sacrificial) anodes. The anode may be arranged in a hole in the enforced (reinforced) concrete to be protected, especially wherein walls of the hole are provided with the electrically conductive layer.

**[0030]** A total weight of the sacrificial anode may especially be at least 50 grams, such as at least 100 grams, especially in embodiments at least 500 grams.

**[0031]** In embodiments e.g. a pre-assembled (sub) assembly is shaped like a flat assembly comprises a first layer comprising (consisting of) the anode and a second layer comprising (consisting of) the (adhesive) electrolytic material, wherein the first layer has a thickness of 250 $\mu$m-5 mm and the second layer has a thickness of 0.5-2 mm. Such pre-assembled assembly may have a surface area (perpendicular to the thickness) of one or several square decimeters up to 10 or more than 10 (e.g. 25 or 100) square meters. The surface area may in specific embodiments be in the range of 100 $cm^2$ to 10 $m^2$.

**[0032]** The pre-assembled (sub) assembly may advantageously be connected to a reinforced concrete comprising the electrically conductive layer, especially wherein the electrolytic material in provided (electrolytically connected) to the electrically conductive layer and especially wherein the anode is electrically connected to the reinforcement material. Hence, in a further aspect the invention provides the pre-assembled (sub) assembly. The pre-assembled assembly is especially a subassembly of the anode assembly of the invention.

**[0033]** In yet a further aspect, the invention provides a (steel) reinforced concrete comprising an electrically conductive layer at a surface of the reinforced concrete, especially the electrically conductive layer described herein (especially the electrically conductive layer being (electrolytically) connected to the surface of the reinforced concrete). In embodiments, the electrically conductive layer comprises the (thermally) sprayed coating (layer).

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0034]** The objects and advantages of the present invention may become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which: FIG. 1 shows a schematic exploded view of a reinforced concrete slab and the components of an embodiment of an anode assembly according to the invention; and FIG. 2 shows a schematic cross section of a part of a concrete structure that includes another embodiment of the anode assembly according to the invention comprising an embedded sacrificial anode.

**[0035]** The schematic drawings are not necessarily to scale. In this description and in the drawings identical or similar parts have been designated with identical or similar reference numbers. It is noted that similar parts in the figures may have been drafted using different patterns.

## DETAILED DESCRIPTION OF THE INVENTION

**[0036]** The present invention comprises an improved method and anode assembly for the application of a sacrificial anode corrosion control system for steel in concrete.

**[0037]** The anode assembly according to the invention comprises an electrically conductive layer for application on the surface of a material to be protected, especially a steel reinforced concrete structure. This electrically conductive layer may, e.g., comprise a conductive coating or mortar or a metallized layer or any other electrically conductive material that can be applied on a concrete surface through for example cold or thermal spraying. In addition, the anode assembly according to the invention especially comprises electrode material, fully or partially, embedded in, covered with or attached to an anode activating electrolyte. The anode activating electrolyte may be solid, semi-solid or liquid whereby the viscosity of the liquid may vary within a wide range.

**[0038]** FIG. 1 shows a schematic exploded view of a reinforced concrete 2 slab and the components of an embodiment of an anode assembly 10 according to the invention. In this embodiment, the assembly 10 comprises an electrically conductive layer 1 which may also be referred to as an electrically conductive coating 1, or an electrically conductive layer 1, that is attached to the surface of (a) reinforced concrete (slab) 2. The conductive layer 1 is especially electrolytically connected to the reinforced concrete (slab) 2. On top of the electrically conductive coating 1, a layer of electrolytically or ion-conductive material 3, hereinafter also referred to as the "electrolytic material" 3, is applied which only covers a small part of the surface area (of the concrete 2) that is coated with the electrically conductive coating 1. It should be noted that, whereas an ion-conductive material 3 may be electrically conductive, an electrically conductive coating 1 used in the anode assembly 10 according to the invention normally will not comprise ion conductivity. The electrically conductive coating 1 material is especially selected for being conductive for electricity (electrons). Yet, the electrolytic material 3 is especially selected for being conductive to ions. Hence, an ion current may especially flow through the electrolytic material 3 and an electric current may especially flow through the electrically conductive coating 1 (to provide the cathodic protection by galvanic action).

**[0039]** The (total) surface area of the electrolytic material 3 (contacting the electrically conductive layer 1) (or contacting area of the electrically conductive layer 1 with the concrete) is especially smaller than the (total) surface area of the electrically conductive layer 1. Especially only a part of a total surface area of the electrically conductive layer 1 is in contact with (or covered by) the electrolytic material 3. The (total) contacting area of the electrolytic material 3 with the electrically conductive layer 1 relative to the total surface area of the electrically conductive layer 1 may in embodiments be equal to or less than 50%, such as equal to or less than 30%, especially equal to or less than 25%, even more especially equal to or less than 20%, such as equal to or less than 15%. In specific embodiments the (total) surface area of the electrolytic material 3 contacting the electrically conductive layer 1 is equal to or smaller than 15% of a surface area (of the concrete 2) that is coated with the electrically conductive layer 1. Yet, in further embodiments of the anode assembly 10 according to the invention the surface area of the ion-conductive material 3 comprises approximately one hundredth of the surface area of the electrically conductive coating 1. In further embodiments, the surface area of the electrolytic material 3 (or contacting area of the electrolytic material 3 with the electrically conductive layer 1) may especially be equal to or less than 10% of the surface area of the electrically conductive layer 1 (or contacting area of the electrically conductive layer 1 with the concrete 2), especially equal to or less than 5%, even more especially equal to or less than 2%, such as equal to or less than 1%, and especially more than 0.01%, such a at least 0.1%. On top of the ion-conductive material 3 a sacrificial anode 4 is placed. The sacrificial anode 4 may in embodiments comprise zinc, aluminium, magnesium and/or any of their alloys, for instance in the form of a strip. The sacrificial anode 4 is not restricted to strip and can have any shape or form that is suitable.

**[0040]** FIG. 2 shows a schematic representation of a cross section of another embodiment of the sacrificial anode corrosion control assembly 10 for reinforced concrete 2 according to the invention. In this embodiment the anode assembly 10 comprises a sacrificial anode 4 that is installed in a hole 5 in the concrete slab 2. The surface of the concrete slab 2 including the wall of the hole 5 is coated with the electrically conductive coating 1.

**[0041]** Although not shown in the figures, it will be understood that the anode 4 is further in direct electric connection with the reinforcement metal (steel) in the concrete. For instance an electrically conductive wire, bar, or plate may be arranged to connect the anode 4 to the steel.

**[0042]** If the sacrificial anode 4 is not applied directly on the surface of reinforced concrete or in a pre-drilled hole, cavity, slot, slit, recess or any other type of opening in the concrete extending from the concrete surface inwards which opening is suitable for installation of at least a part of an anode 4 in the reinforced concrete 2, it can for instance be used in a pre-fabricated anode (sub) assembly. In such pre-fabricated anode sub assembly, the anode 4 and ion-conductive material 3 may have been pre-assembled.

**[0043]** In the remainder of this description and/or in the claims the use of the term "hole" may refer to any opening 5 in the concrete that is suitable for installing an anode in it and such an opening 5 may comprise for example a cavity, slot, slit or recess.

**[0044]** The cathodic protection with the assembly 10 of the invention is especially based on a series of coupled redox reactions and transport of electrons and ions. This especially relates to a first oxidation (or anodic) reaction at the interface between the sacrificial anode 4 and the electrolytic material 3, a first reduction (or cathodic) reaction at the interface of the steel with the concrete 2; a second oxidation reaction at the interface between the concrete 2 and the electrically conductive layer 1; and a second reduction reaction at the interface between the electrically conductive layer and the electrolytic material. Without being bound to theory, possible reactions that are anticipated are:

1st oxidation: $Me \rightarrow Me^{n+} + n \cdot e^-$;

1st reduction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$;

2nd oxidation: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$; and

(continued)

2nd reduction: $O_2 + 2H_2O + 4e^- \rightarrow 4OH$

**[0045]** Yet, also other reaction may take place. Furthermore, in the electrolytes and at the surfaces also further reactions may take place, such as formation of complexes, e.g., from ions. Essentially, electrons and ions are released or consumed in the reactions. The electrons may be transported from the locations (interfaces) where they are released to the locations where they are consumed directly as an electric current via the electrically conductive materials, i.e., through the anode 4, and from the anode 4, via the electric connection to the steel, and from the side of the electrically conductive layer 1 contacting the concrete 2, through the conductive layer 1 to the other side contacting the electrolytic material 3. The electrons may further be transported through the electrolytes, i.e. the concrete 2 and the electrolytic material 3 by means of the ion transport, to close the (galvanic) circuit.

**[0046]** In the (above) description and in the claims the term electrically conductive coating or layer 1 shall be construed to also include the possibility of a coating or layer in the form of for example an electrically conductive mortar or metallized film.

**[0047]** In yet a further aspect, the invention provides a method for cathodic protection of (steel) reinforced concrete, wherein the method comprises (i) providing an electrically conductive layer at a surface of the reinforced concrete, especially wherein the electrically conductive layer electrolytically contacts the concrete; (ii) providing an electrolytic material to the electrically conductive layer, especially wherein the electrolytic material (electrolytically) contacts the electrically conductive layer; (iii) providing a sacrificial anode to the electrolytic material, especially remote from the electrically conductive layer, especially wherein the anode electrolytically contacts the electrically conductive layer. The sacrificial anode is especially provided such that the sacrificial anode (directly) contacts the electrolytic material. The sacrificial anode is especially provided in such a way that the sacrificial anode is not (directly) contacting the electrically conductive layer, especially avoiding a short circuit between anode and the electric conductive material.

**[0048]** In further embodiments, the method comprises electrically connecting the sacrificial anode to reinforcement material in the reinforced concrete. The reinforcement material is especially a steel reinforcement material, e.g. a steel reinforcement cage.

**[0049]** In a further specific embodiment, the method comprises applying the anode assembly as described herein to the concrete. In embodiments a pre-assembled anode/electrolytic material combination (or pre-assembled assembly) is used. In embodiments, a pre-assembled anode/electrolytic material combination (pre-assembled assembly) is provided to the electrically conducting layer. In specific embodiments, the electrolytic material comprises an adhesive electrolytic material and wherein the sacrificial anode is bond to the electrically conductive layer with the electrolytic material.

**[0050]** In further specific embodiments, the electrically conductive layer is provided to the concrete by coating, especially by spray coating. In specific embodiments, the method comprises thermally spray coating the electrically conductive layer at the reinforced concrete.

**[0051]** In specific embodiments, the method further comprises providing an opening in the concrete prior to providing an electrically conductive layer at a surface of the reinforced concrete, and wherein (i) during providing the electrically conductive layer at the surface of the reinforced concrete, the electrically conductive layer is also provided to the opening (ii) the electrolytic material is at least partly provided to the electrically conductive layer in the opening, and (iii) the sacrificial anode is at least partly provided in the opening to the electrolytic material.

**[0052]** The method may comprise installing the anode in the opening and optionally closing the opening (such as with concrete) again after installing the anode.

**[0053]** The invention further provides (an object comprising) a cathodic protected (steel) reinforced concrete obtainable by the method described herein. The object may e.g. comprise a bridge (deck), a (concrete) pile, pole, or rod. The object may in further embodiments comprise a bridge deck support, a cantilever. The object may comprise a balcony or a balcony supports. The object may further comprise a concrete beam or pillar. The object may be a (concrete comprising or concrete) jetty, pier (or a support for such jetty or pier). The object may further especially comprise any kind of different concrete slabs of which the supports, piles or pillars are partly submerged in sea- or fresh water.

**[0054]** In a further aspect the invention provides (steel) reinforced concrete, wherein an anode assembly described herein is (functionally) connected to the (steel) reinforced concrete. The term "functionally connected" with respect to the anode assembly especially relates to an anode assembly wherein the conductive coating is (electrolytically) connected to the concrete and the anode is (electrically) connected to the reinforcement material (steel).

**[0055]** The invention further provides an object comprising (steel) reinforced concrete, wherein an anode assembly described herein is (functionally) connected to the (steel) reinforced concrete. The object may e.g. comprise an object described above.

**[0056]** The advantages of the anode assembly according to the invention compared to sacrificial anodes or anode assemblies for reinforced concrete according to the prior art, can be summarized among others as follows:

- By applying an electrically conductive coating on the concrete surface prior to installation of a sacrificial anode, the anode assembly according to the invention may be able to distribute the (electric) current over an expanded surface area.
- By applying an electrically conductive coating 1 on the concrete surface, the anode assembly according to the invention may be able to reduce the effect of the concrete's high electrical resistance which normally will restrict the sacrificial anode's throwing power.
- The pre-fabricated anode assembly according to the invention can be applied directly on the concrete surface by virtue of the salt bridge effect of an ion-conductive material 3. In various embodiments the ion-conductive material 3 is applied in the form of an adhesive and no additional concrete pre- or post-treatment is required. In further embodiments, the sacrificial anode 4 may be connected to the electrically conductive coating 1 by means of the electrolytic material 3. In specific embodiments, the assembly of the sacrificial anode 4 and the electrolytic material 3 are connected (sticked/bond) to the electrically conductive coating by means of the electrolytic material.

**[0057]** The term "plurality" refers to two or more. Furthermore, the terms "a plurality of" and "a number of" may be used interchangeably. The terms "substantially" or "essentially" herein, and similar terms, will be understood by the person skilled in the art. The terms "substantially" or "essentially" may also include embodiments with "entirely", "completely", "all", etc. Hence, in embodiments the adjective substantially or essentially may also be removed. Where applicable, the term "substantially" or the term "essentially" may also relate to 90% or higher, such as 95% or higher, especially 99% or higher, even more especially 99.5% or higher, including 100%. For numerical values it is to be understood that the terms "substantially", "essentially", "about", and "approximately" may also relate to the range of 90% - 110%, such as 95%-105%, especially 99%-101% of the values(s) it refers to.

**[0058]** The term "comprise" includes also embodiments wherein the term "comprises" means "consists of". The term "comprising" may in an embodiment refer to "consisting of" but may in another embodiment also refer to "containing at least the defined species and optionally one or more other species". Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim.

**[0059]** The term "and/or" especially relates to one or more of the items mentioned before and after "and/or". For instance, a phrase "item 1 and/or item 2" and similar phrases may relate to one or more of item 1 and item 2.

**[0060]** Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

**[0061]** The devices, apparatus, or systems may herein amongst others be described during operation. As will be clear to the person skilled in the art, the invention is not limited to methods of operation, or devices, apparatus, or systems in operation.

**[0062]** The term "further embodiment" and similar terms may refer to an embodiment comprising the features of the previously discussed embodiment, but may also refer to an alternative embodiment. It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims.

**[0063]** In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim.

**[0064]** Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising", and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to".

**[0065]** While only certain features of the invention have been described herein, many modifications and changes will occur to those skilled in the art, the invention being defined only by the appended claims.

**[0066]** It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims.

**[0067]** The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

**[0068]** The invention further pertains to assemblies comprising one or more of the characterizing features described in the description.

**[0069]** The various aspects discussed in this application can be combined in order to provide additional advantages. Further, the person skilled in the art will understand that embodiments can be combined, and that also more than two embodiments can be combined.

## Claims

1. An anode assembly (10) for sacrificial anode based cathodic protection of reinforced concrete (2), the anode assembly comprising (i) a sacrificial anode (4), (ii) an electrically conductive layer (1), and (iii) an electrolytic material (3), wherein

   - the electrically conductive layer (1) is configured for providing at a surface of the reinforced concrete (2) to be protected,
   - the electrolytic material (3) is connected to the electrically conductive layer (1),
   - the electrolytic material (3) electrolytically connects the sacrificial anode (4) to the electrically conductive layer (1).

2. The anode assembly (10) according to claim 1, wherein the sacrificial anode (4) contacts the electrolytic material (3) at a first side of the electrolytic material (3), and the electrically conductive layer (1) contacts the electrolyte at another side of the electrolytic material (3)..

3. The anode assembly (10) according to claim 1 or claim 2, wherein the electrically conductive layer (1) comprises one or more of expanded metal, a film, a coating, a mesh, a strip, an electrically conductive mortar and a metallized layer.

4. The anode assembly (10) according to any one of the preceding claims, wherein the electrically conductive layer (1) comprises a thermally sprayed coating, wherein a thickness of the electrically conductive layer (1) is in the range of 100-5000 $\mu$m.

5. The anode assembly (10) according to any one of the preceding claims, wherein the electrolytic material (3) comprises an adhesive electrolytic material.

6. The anode assembly (10) according to any one of the preceding claims, wherein a surface area contacting the electrically conductive layer (1) of the electrolytic material (3) is equal to or smaller than 15% of a surface area that is coated with the electrically conductive layer (1).

7. The anode assembly (10) according to any one of the preceding claims, wherein the sacrificial anode (4) is arranged in a hole (5) in the reinforced concrete (2) to be protected.

8. The anode assembly (10) according to any one of the preceding claims, wherein the sacrificial anode (4) and the electrolytic material (3) applied in the anode assembly (10) define a pre-assembled sub assembly.

9. An object comprising reinforced concrete (2), wherein an anode assembly (10) according to any one of the preceding claims is functionally connected to the reinforced concrete (2).

**10.** A method for cathodic protection of reinforced concrete (2), wherein the method comprises:

- providing an electrically conductive layer (1) at a surface of the reinforced concrete (2);
- providing an electrolytic material (3) to the electrically conductive layer (1),
- providing a sacrificial anode (4) to the electrolytic material (3), remote from the electrically conductive layer (1); and
- electrically connecting the sacrificial anode (4) to reinforcement material in the reinforced concrete (2).

**11.** The method according to claim 10, wherein electrolytic material (3) comprises an adhesive electrolytic material and wherein the sacrificial anode (3) is bond to the electrically conductive layer (1) with the electrolytic material (3).

**12.** The method according to any one of the claims 10-11, comprising thermally spray coating the electrically conductive layer (1) at the reinforced concrete (2).

**Patentansprüche**

**1.** Anodenanordnung (10) zum kathodischen Schutz von verstärktem Beton (2) auf Opferanodenbasis, wobei die Anodenanordnung (i) eine Opferanode (4), (ii) eine elektrisch leitfähige Schicht (1) und (iii) ein Elektrolytmaterial (3) umfasst, wobei

- die elektrisch leitfähige Schicht (1) ausgestaltet ist, um an einer Oberfläche des zu schützenden verstärkten Betons (2) bereitgestellt zu werden,
- das Elektrolytmaterial (3) mit der elektrisch leitfähigen Schicht (1) verbunden ist,
- das Elektrolytmaterial (3) die Opferanode (4) elektrolytisch mit der elektrisch leitfähigen Schicht (1) verbindet.

**2.** Anodenanordnung (10) nach Anspruch 1, wobei die Opferanode (4) das Elektrolytmaterial (3) an einer ersten Seite des Elektrolytmaterials (3) kontaktiert und die elektrisch leitfähige Schicht (1) den Elektrolyten an einer anderen Seite des Elektrolytmaterials (3) kontaktiert.

**3.** Anodenanordnung (10) nach Anspruch 1 oder Anspruch 2, wobei die elektrisch leitfähige Schicht (1) ein oder mehrere von expandiertem Metall, einem Film, einer Beschichtung, einem Maschenmaterial, einem Streifen, einem elektrisch leitfähigen Mörtel und einer metallisierten Schicht umfasst.

**4.** Anodenanordnung (10) nach einem der vorhergehenden Ansprüche, wobei die elektrisch leitfähige Schicht (1) eine thermisch gespritzte Beschichtung umfasst, wobei eine Dicke der elektrisch leitfähigen Schicht (1) im Bereich von 100 bis 5000 $\mu$m liegt.

**5.** Anodenanordnung (10) nach einem der vorhergehenden Ansprüche, wobei das Elektrolytmaterial (3) ein klebendes Elektrolytmaterial umfasst.

**6.** Anodenanordnung (10) nach einem der vorhergehenden Ansprüche, wobei ein Flächeninhalt, der die elektrisch leitfähige Schicht (1) des Elektrolytmaterials (3) kontaktiert, gleich oder kleiner als 15 % eines Flächeninhalts ist, der mit der elektrisch leitfähigen Schicht (1) beschichtet ist.

**7.** Anodenanordnung (10) nach einem der vorhergehenden Ansprüche, wobei die Opferanode (4) in einem Loch (5) in dem zu schützenden verstärkten Beton (2) angeordnet ist.

**8.** Anodenanordnung (10) nach einem der vorhergehenden Ansprüche, wobei die Opferanode (4) und das Elektrolytmaterial (3), die in der Anodenanordnung (10) aufgebracht werden, eine vormontierte Teilanordnung definieren.

**9.** Objekt, umfassend verstärkten Beton (2), wobei eine Anodenanordnung (10) gemäß einem der vorhergehenden Ansprüche funktionell mit dem verstärkten Beton (2) verbunden ist.

**10.** Verfahren zum kathodischen Schützen von verstärktem Beton (2), wobei das Verfahren umfasst:

- Bereitstellen einer elektrisch leitfähigen Schicht (1) an einer Oberfläche des verstärkten Betons (2);
- Bereitstellen eines Elektrolytmaterial (3) an die elektrisch leitfähige Schicht (1),
- Bereitstellen einer Opferanode (4) an das Elektrolytmaterial (3) entfernt von der elektrisch leitfähigen Schicht (1); und
- elektrisches Verbinden der Opferanode (4) mit dem Verstärkungsmaterial in dem verstärkten Beton (2).

**11.** Verfahren nach Anspruch 10, wobei Elektrolytmaterial (3) ein klebendes Elektrolytmaterial umfasst, und wobei die Opferanode (3) mit dem Elektrolytmaterial (3) an die elektrisch leitfähige Schicht (1) gebondet ist.

**12.** Verfahren nach einem der Ansprüche 10 bis 11, umfassend thermisches Spritzbeschichten der elektrisch leitfähigen Schicht (1) an den verstärkten Beton (2).

## Revendications

**1.** Ensemble anodique (10) pour la protection cathodique basée sur une anode sacrificielle de béton armé (2), l'ensemble anodique comprenant (i) une anode sacrificielle (4), (ii) une couche électriquement conductrice (1), et (iii) un matériau électrolytique (3), dans lequel

- la couche électriquement conductrice (1) est configurée pour être appliquée à une surface du béton armé (2) à protéger,
- le matériau électrolytique (3) est raccordé à la couche électriquement conductrice (1),
- le matériau électrolytique (3) raccorde électriquement l'anode sacrificielle (4) à la couche électriquement conductrice (1).

**2.** Ensemble anodique (10) selon la revendication 1, dans lequel l'anode sacrificielle (4) est en contact avec le matériau électrolytique (3) sur un premier côté du matériau électrolytique (3), et la couche électriquement conductrice (1) est en contact avec l'électrolyte (3) sur un autre côté du matériau électrolytique (3).

**3.** Ensemble anodique (10) selon la revendication 1 ou la revendication 2, dans lequel la couche électriquement conductrice (1) comprend un ou plusieurs éléments parmi un métal déployé, un film, un revêtement, un treillis, une bande, un mortier électriquement conducteur et une couche métallisée.

**4.** Ensemble anodique (10) selon l'une quelconque des revendications précédentes, dans lequel la couche électriquement conductrice (1) comprend un revêtement projeté thermiquement, dans lequel une épaisseur de la couche électriquement conductrice (1) se situe dans la plage de 100-5000 μm.

**5.** Ensemble anodique (10) selon l'une quelconque des revendications précédentes, dans lequel le matériau électrolytique (3) comprend un matériau électrolytique adhésif.

**6.** Ensemble anodique (10) selon l'une quelconque des revendications précédentes, dans lequel une superficie en contact avec la couche électriquement conductrice (1) du matériau électrolytique (3) est égale ou inférieure à 15 % d'une superficie qui est recouverte par la couche électriquement conductrice (1).

**7.** Ensemble anodique (10) selon l'une quelconque des revendications précédentes, dans lequel l'anode sacrificielle (4) est disposée dans un trou (5) dans le béton armé (2) à protéger.

**8.** Ensemble anodique (10) selon l'une quelconque des revendications précédentes, dans lequel l'anode sacrificielle (4) et le matériau électrolytique (3) appliqués dans l'ensemble anodique (10) définissent un sous-ensemble préassemblé.

**9.** Objet comprenant du béton armé (2), dans lequel un ensemble anodique (10) selon l'une quelconque des revendications précédentes est fonctionnellement raccordé au béton armé (2).

**10.** Procédé de protection cathodique de béton armé (2), le procédé comprenant :

- l'application d'une couche électriquement conductrice (1) à une surface du béton armé (2) ;
- l'application d'un matériau électrolytique (3) à la couche électriquement conductrice (1) ;
- l'application d'une anode sacrificielle (4) au matériau électrolytique (3), à distance de la couche électriquement conductrice (1) ; et
- le raccordement électrique de l'anode sacrificielle (4) à un matériau de renforcement dans le béton armé (2).

**11.** Procédé selon la revendication 10, dans lequel le matériau électrolytique (3) comprend un matériau électrolytique adhésif et dans lequel l'anode sacrificielle (3) est collée à la couche électriquement conductrice (1) avec le matériau électrolytique (3).

**12.** Procédé selon l'une quelconque des revendications 10 et 11, comprenant le dépôt par projection thermique de la couche électriquement conductrice (1) sur le béton armé (2).

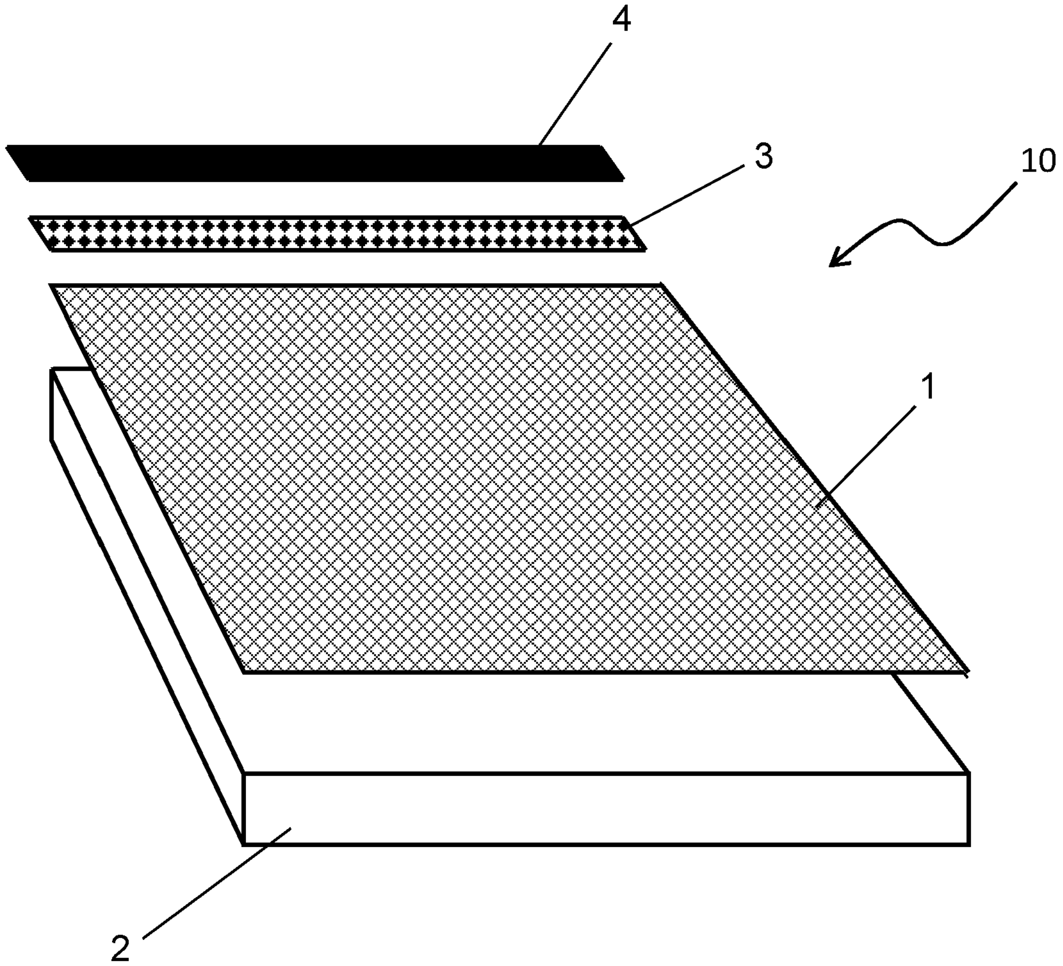


FIG. 1

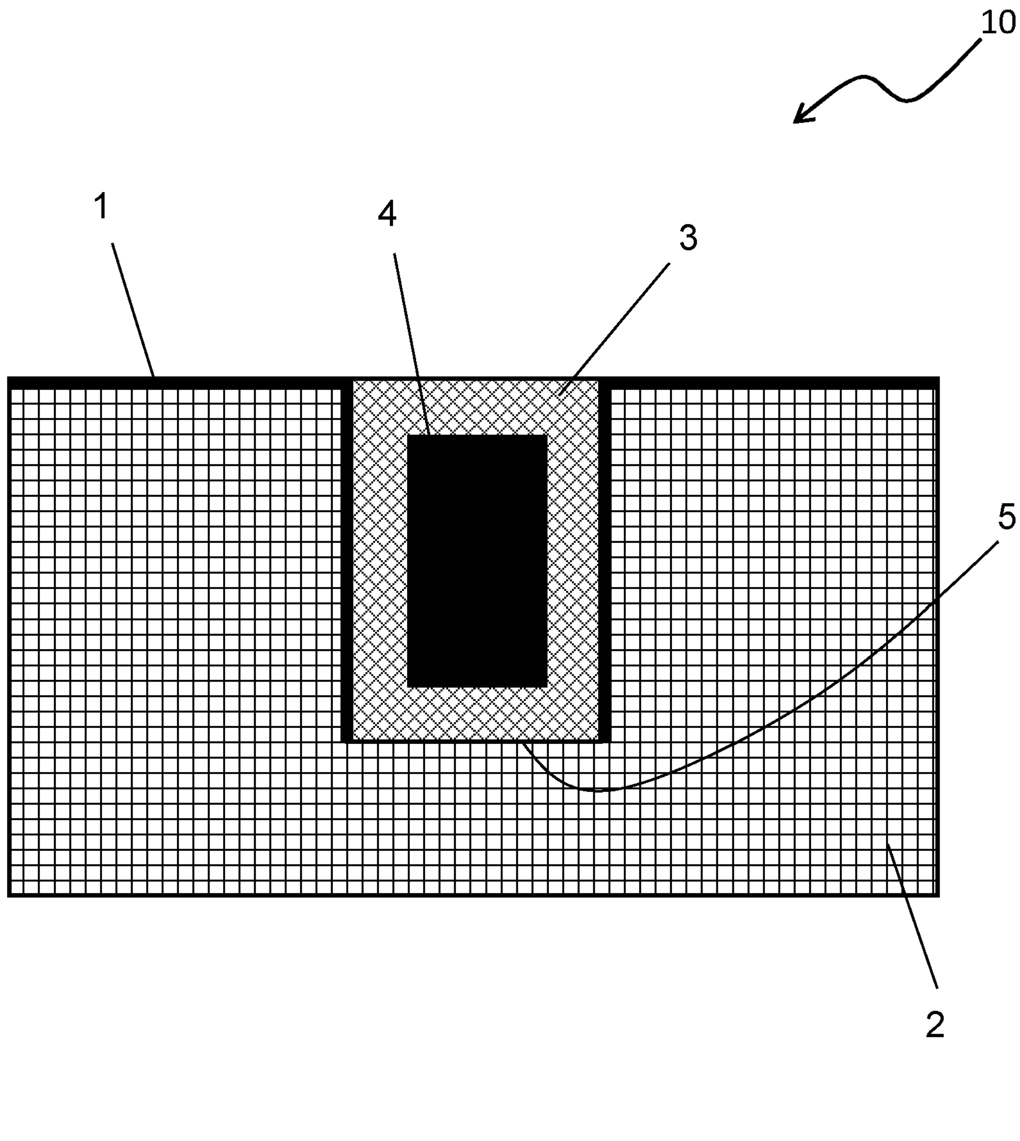


FIG. 2

## REFERENCES CITED IN THE DESCRIPTION



### Patent documents cited in the description


- US 2014027306 A **[0003]**
- US 2013015058 A **[0003]**