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(54) Titre : MATERIAU METALLIQUE RECOUVERT D'APATITE, PROCEDE DE PREPARATION ET UTILISATION
(54) Title: APATITE-COATED METALLIC MATERIAL, PROCESS FOR ITS PREPARATION, AND ITS USE

(57) Abrégé/Abstract:
The invention relates to a novel apatite-coated metallic material having improved surface quality and biocompatibility, a process for its preparation, and the use of the material for bone implants, in particular dental implants, artificial joints and fixative material for accident surgery (osteosynthesis material). The coating in this case consists of a thick covering of hydroxyapatite crystals and/or amorphous calcium phosphate spheres having a specific surface area of less than 15 m^2/g.

Abstract

The invention relates to a novel apatite-coated metallic material having improved surface quality and biocompatibility, a process for its preparation, and the use of the material for bone implants, in particular dental implants, artificial joints and fixative material for accident surgery (osteosynthesis material). The coating in this case consists of a thick covering of hydroxyapatite crystals and/or amorphous calcium phosphate spheres having a specific surface area of less than 15 m^2/g.

Apatite-coated metallic material, process for its preparation, and its use

The invention relates to a novel apatite-coated metallic material having improved surface quality and biocompatibility, a process for its preparation, and the use of the material for bone implants, in particular dental implants, artificial joints and fixative material for accident surgery (osteosynthesis material).

It is known that coated implants integrate better with calcium phosphate, in particular with the bone mineral hydroxyapatite (HAP ($Ca_{10}(PO_4)6OH$)). Different processes are used for coating implants with calcium phosphate, such as, for example, plasma injection, sol-gel processes, electrophoresis, electrochemically assisted deposition.

Electrochemically assisted deposition has advantages compared with other processes on account of the possibility of the production of uniform (even with very rough surfaces) and thin layers, the possibility of the specific control of the phases to be deposited by means of electrical parameters, and produces lower costs in preparation.

In electrochemically assisted deposition, calcium phosphate precipitates on the cathode, which forms the implant. The resulting layer is very porous and can therefore be removed easily from the surface. There are various possibilities for decreasing the porosity.

According to **US 3892648**, an emulsion of bone powder and collagen is applied electrochemically to the metallic implant and a stronger adhesion is achieved therewith by means of the collagen.

In **DE 19504386 A1**, the deposited calcium phosphate

layer is combined in graded form with the metal surface. Calcium phosphate crystals are surrounded by a growing oxide layer. A disadvantage of this process is: it functions only with implants of titanium or titanium alloys. The porosity of the coating is not lowered and the mechanical properties are thus not improved.

In the patent **US 5458863**, using an electrochemically assisted deposition, a brushite layer is first produced, which is then converted to hydroxyapatite at temperatures between 20 and 100°C. The adhesion between layer and substrate is improved by regular removal of gas bubbles on the substrate surface during the coating. It is disadvantageous in this process that the conversion process lasts about 36 hours. At temperatures of 750°C, according to **WO 9813539**, hydroxyapatite crystals are formed from the electrochemically assisted deposition of a calcium phosphate phase and the adhesion is improved. Here, the higher temperatures are especially to be mentioned as particularly disadvantageous. In the patent **US 5205921**, after the electrolytic deposition the adhesion of the layer produced is improved by means of ultrasonic processes in a methanol bath. The method is based on the fact that crystallites having low adhesion to the substrate are detached again by the influence of ultrasound.

There is still a great need for implant materials having an improved surface and compatibility with the biological system.

The object of the invention is therefore an apatite-coated metallic material having decreased porosity and improved adhesion.

According to the invention, the object is achieved by means of an apatite-coated metallic material, in which the coating consists of a thick covering of

hydroxyapatite crystals having a needle length in the range from 200 to 300 nm or amorphous calcium phosphate spheres having a diameter in the range from 35 to 200 nm with a layer thickness of > 1 µm and the coating has a specific surface area of less than 15 m^2/g.

The metallic material consists of titanium or titanium alloys, CoCrMo alloys or stainless steels.

According to the invention, the novel apatite-coated material is dissolved by means of an electrochemically assisted process using a substrate electrode formed from the metallic material and a counterelectrode in which, as electrolyte, an aqueous solution containing calcium and phosphate ions is used.

According to the invention, the coating is carried out by cathodic polarization in a number of successive process cycles. A process cycle consists of cathodic polarization in one or more successive steps with identical or different high constant current densities, and a rinsing and/or drying phase following thereon.

The concentration ratio of calcium and phosphate ions in the electrolyte corresponds to that of hydroxyapatite.

By means of the process according to the invention, a decrease in the porosity takes place in that the process is repeated two or more times in a number of cycles with electrochemical calcium phosphate deposition and subsequent rinsing and/or drying.

Electrochemically, hydroxyapatite or its precursors (amorphous calcium phosphate (ACP)/mixed states of ACP/HAP) are deposited on the metallic material. The size of the hydroxyapatite crystals is between 200 and 300 nm. The amorphous spheres can be varied in their diameter in the range from 35 to 200 nm. The compressed

layers are achieved by an exchange between short coating phases and rinsing and/or drying phases following thereon. The drying is carried out at room temperature. During the drying, the used electrolyte liquid is stripped off the porous layers. On the next immersion, the cavities fill with fresh electro-lyte liquid. An electrochemically assisted deposition of calcium phosphate phases thus also takes place in the cavities. Moreover, the material body is moved continuously during the coating and drying phases in order to obtain a uniform coating, even with specially shaped material bodies and very rough/porous surfaces.

In one embodiment of the process according to invention, the cathodic polarization takes place at a constant current density of 0.5 mA/cm^2 to 20 mA/cm^2 or in the individual process cycles at different current densities, the current density being decreased in the subsequent cycles.

The invention also comprises the use of the novel apatite-coated metallic materials for the production of implants, in particular dental and joint implants, and material for the stabilization of the bone in fractures (osteosynthesis material).

The invention is illustrated in greater detail with the aid of the following working examples:

Working example 1

Coating sample: Cylinder of titanium alloy ($TiAl_6V_4$), 10 mm diameter, 46 mm long, ground with SIC paper, 1200 grit.

This sample was cleaned in ethanol using ultrasound before coating, rinsed off with deionized water, dried by means of a stream of air, then covered on both ends with a holder including a contact device of Deguform

silicone material. The area to be coated was 6.28 cm^2.

The electrolyte liquid was prepared from 5 litres of deionized water with 2.455 g of $CaCl_2*2H_2O$ and 1.15 g of $NH_4H_2PO_4$ introduced, which corresponds to a Ca/P ratio of 1.67. The temperature of the electrolyte liquid which was controlled by means of a thermostat was 37°C. The pH was adjusted to 6.45 using an NH_4OH solution.

The sample is polarized as a cathode; platinum gauze electrodes were used as the anode. The coating took place in 10 cycles. One cycle comprised:

Cathodic polarization for five minutes with a constant current of 63 mA, then rinsing for 1 minute in deionized water and then drying for 5 minutes with a fan.

Results:

Fig. 1 shows a scanning electron micrograph of the apatite coating obtained according to Working example 1 on $TiAl_6V_4$. Macroscopically, the layer appears to be uniformly white and adheres well. The investigation on the scanning electron micrograph shows a closed layer with apatite-like needles of about 200 - 300 nm length. The energy-dispersive X-ray analysis shows a Ca/P ratio of 1.67, which corresponds to hydroxyapatite. The BET analysis according to DIN 66 131 shows a specific surface area of 9.25 square metres per gram. In comparison to this, in the case of a non-compressed deposition a specific surface area of about 60 square metres/gram is achieved. By means of etching and skew analysis in the scanning electron micrograph, the layer thickness was measured as about 1.8 µm.

An IR-spectroscopic analysis (FTIR) confirms that the coating is hydroxyapatite. The IR spectra of hydroxyapatite powders from Merck and of the coated sample

have identical absorption bands.

Fig. 2 shows a scanning electron micrograph of the apatite coating obtained according to Working example 1 on $TiAl_6V_4$ which has been mechanically detached from the substrate surface. On the bottom of the coating (substrate side) an area of high density can be discerned, which decreases in the layer surface direction.

Working example 2

Identical sample size, coating and results as in Working example 1. However, the sample material is the alloy $CoCr_{28}Mo$.

Working example 3

Identical sample size, coating as in Working example 1. However, within the process cycles the polarization was carried out in two stages with the following current densities:

1 minute at 75 mA, 4 minutes at 50 mA.

Results: needle length about 200-300 nm, even tighter packing.

Working example 4

Identical sample size, coating as in Working example 1. However, in the course of the 5-minute cathodic polarization, the current was altered as follows in cycles 1, 3 and 8: 1 min at 63 mA, 4 min at 5.6 mA. In cycles 2, 4, 5, 6, 7, 9, 10, the current was 5.6 mA.

Fig. 3 shows a scanning electron micrograph of the coating obtained according to Working example 3. Macroscopically, the layer appears uniformly white and

adheres well. The investigation in the scanning electron micrograph shows a closed layer with calcium phosphate spheres of about 50 to 150 nm diameter. By means of etching and skew analysis in the scanning electron micrograph, the layer thickness was measured as about 1.8 µm.

Working example 5

Identical sample size, coating as in Working example 1, but in 25 cycles. A cycle comprises: 1-minute cathodic polarization at 63 mA, 1 min at 50 mA.

Result: mixing state (ACP spheres and HAP needles). See Fig. 4

Fig. 4 shows a scanning electron micrograph of the coating obtained according to Working example 5. Macroscopically, the coating appears uniformly white and adheres well. The investigation in the scanning electron micrograph shows a closed layer with calcium phosphate spheres and hydroxyapatite needles.

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CLAIMS:

1. An apatite-coated metallic material, comprising a metallic material and a coating thereon comprising a thick covering of hydroxyapatite crystals having a needle length in the range from 200 to 300 nm, of amorphous calcium phosphate spheres having a diameter in the range of from 35 to 200 nm, or of a combination thereof, wherein the coating has a specific surface area of less than 15 m^2/g and a thickness greater than 1 µm.

2. The material according to claim 1, wherein the metallic material consists of titanium, a titanium alloy, a CoCrMo alloy or a stainless steel.

3. A process for the preparation of an apatite-coated metallic material by an electrochemically assisted process using a substrate electrode formed from the metallic material and a counterelectrode in which, as electrolyte, an aqueous solution containing calcium and phosphate ions is used, wherein a cathodic polarization takes place in a number of successive process cycles, a process cycle of cathodic polarization consisting in one or more successive stages having identical or different high constant current densities and a rinsing phase, a drying phase, or both a rinsing and a drying phase, following thereon.

4. The process according to claim 3, wherein the concentration ratio of calcium and phosphate ions in the electrolyte corresponds to that of hydroxyapatite.

5. The process according to claim 3 or 4, wherein the material is constantly turned during the process cycles.

6. The process according to any one of claims 3 to 5, wherein the cathodic polarization is carried out at a

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constant current density of 0.5 mA/cm^2 to 20 mA/cm^2 or takes place in the individual process cycles at different current densities, the current density being decreased in the subsequent cycles.

7. Use of a material according to claim 1 or 2 for the preparation of bone implants, dental implants, artificial joints or fixative material for accident surgery.

8. Use of a material coated according to the process of any one of claims 3 to 6 for the preparation of bone implants, dental implants, artificial joints or fixative material for accident surgery.

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PATENT AGENTS

Application number / numéro de demande: 2388903

Figures: all

Pages: all

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