

BIODEGRADABLE IMPLANTABLE MEDICAL DEVICES FORMED FROM SUPER - PURE MAGNESIUM-BASED MATERIAL

FIELD OF THE INVENTION

The present invention generally relates to an implantable medical device, in particular, a biodegradable endoprosthesis body such as a vessel stent, formed at least partly from a constructional material comprising super-pure magnesium or an alloy thereof further comprising one or more super-pure alloying elements. The super-pure magnesium-based constructional material may be incorporated into an implantable biodegradable endoprosthesis as such, and used in various technical fields.

BACKGROUND OF THE INVENTION

In recent years, an interest in biodegradable (biocorrodible, bioabsorbable etc.) endoprostheses has been observed worldwide. By definition, such devices are capable of being slowly dissolved in living body liquids and completely disappearing over time providing they have the optimum corrosion resistance. Dissolution is concurrent with performance of their medical function and avoids undesirable consequences of their presence in an organism as alien body. By contrast, implanting *in vivo* a "permanent" endoprosthesis made of insoluble material will eventually require surgical re-intervention for its extraction (e.g. bone or coronary surgery), otherwise its continued presence will increase the probability of adverse consequences for a patient such as inflammation, aneurysm, in-stent restenosis or thrombosis etc) in case of vascular stents. Therefore, the interest in biodegradable technology applied to endoprostheses is of relevance to patient care and effectiveness of treatment.

There are a number of early examples of biomaterials for endoprostheses manufacture. One of such examples describes [1]: "...A vessel wall support ..., wherein the first component is at least one metal selected from the group consisting of magnesium, titanium, zirconium, niobium, tantalum, zinc and silicon and the second component is at least one metal selected from the group consisting of lithium, sodium, potassium, manganese calcium and iron". Later, biodegradable metal constructional materials were employed formed as from pure (not alloyed) metals, which included Iron [3-5], Zinc, Magnesium and Molybdenum [5, 6], so and alloys: iron-alloys [5-8], zinc-alloys [5, 6], tungsten-alloys [6] and others. However, researchers subsequently placed emphasis on magnesium alloys as having the most promising characteristics for biodegradable materials. It is known that magnesium is one of the most important elements in the life

cycle of a living body and influences metabolism [9]; magnesium ions are the fourth most abundant metal ions the human body. It is known that an adult man consumes daily 300-400 mg of magnesium; to put this into context, a magnesium stent has a weight only about of 1 mg, consequently, its degradation should not influence magnesium content in the living body. Recently, it has been reported that the presence of magnesium in the human bone structure is beneficial to bone strength and growth [10]. Magnesium alloys have a specific density ($1.7 - 1.9 \text{ g/cm}^3$) and Young's modulus (41–45 GPa) that are close to those of human bone ($1.8\text{--}2.1 \text{ g/cm}^3$, 3–20 GPa), implying some suitable properties for physiological applications.

However, for medical implant applications magnesium-based alloys have low strength and low plasticity due to the hexagonal closed packed (h.c.p.) crystal structure of magnesium-matrix. In addition, magnesium has a low resistance to corrosion because of its strong chemical activity. Thus, the only way to use magnesium as structure materials for biodegradable endoprotheseses is to create magnesium-based alloys with improved combination of mechanical and corrosion properties.

According to ISO 3116:2007 [11] and BS EN 1753:1997 [12], the main alloying elements for industrial magnesium are the following: aluminum (Al), zinc (Zn), manganese (Mn), Silicon (Si), Rare Earth elements (RE), Zirconium (Zr), Silver (Ag), and Yttrium (Y). According to specification ASTM for magnesium alloys [13], the following alloying elements (Al, Ag, Bi, Cu, Cd, Cr, Ca, Fe, Li, Mn, Ni, Pb, RE, Sb, Si, Sn, Sr, Th, Y, Zn, Zr) have been specified for a production of magnesium alloys. Many magnesium-based alloys were developed for last decades for different field of application, some of them – for medical applications, but more often as creep resistant alloys for industrial applications. The basic grades of magnesium-alloys and their modification for different purposes are described in detail in previous applications [14], [40]. A method for the preparation of high purity magnesium is mentioned in US 5,698,158 [37].

Initially, most investigators of biodegradable endoprotheseses have selected industrial magnesium-based alloys as structural materials for endoprotheseses: AE21 [15], AZ21 [16], AZ31 [17, 18], AZ63 [19], AZ91 [18, 20], AZ91D [21], LAE442 [18, 21] and alloy WE43 [18, 22-25]. However, attempts to use industrial magnesium alloys - even with improved properties, such as AZ91D or WE43 - for developing qualitative biosoluble endoprotheseses have not given expected results. During tests *in vivo*, the short time taken for full dissolution of stents made even of the best alloys appears insufficient. For example, in the case of alloy AE21 (domestic pigs test) it was less than 60 days [11], for alloy WE43 (Biotronik AMS stent, human coronary trial) it was much less than 4 months

[26, 27]. An initial inspection using intravascular ultrasound (IVUS), carried out after 4 months, found no traces of stent material. It is clear that both types of stents lost mechanical integrity much earlier than the time taken for full dissolution, in spite of the fact that strut thicknesses were increased up to 150 - 200 microns [11] to compensate for insufficient mechanical properties of alloys and high corrosion rate.

As a consequence of increased thickness, the flexibility of stents with such geometry decreased, and such devices were found difficult to deliver through the vessels system. Therefore, catheters of wider diameters (6F) and predilatation of a vessel were used [28] in order to introduce the endoprosthesis into the damaged segment of a vessel. In addition, more pressure in balloon catheter was necessary to expand stent to the necessary diameter. Moreover, the early loss of a stent mechanical integrity most likely resulted in secondary vessel occlusion by flaps, spasm or thrombosis, and human trials with the Biotronik AMS stent were stopped because the degradation process compromised the scaffolding integrity [29].

So, regardless of a potentiality of magnesium alloys using in the field of biocorrosible endoprostheses, magnesium-based alloys that were tested in trials can be used only to a limited extent because of their poor corrosion resistance and mechanical properties. For achievement of properties that will be more suitable for constructional materials of biodegradable stents, some new non-commercial alloys based on magnesium were developed: Mg-Mn-Zn [30], Mg-Ca [31, 32], Mg-Sc-Y-RE-Zr [14], Mg-In-Sc-Y-RE-Zr [33], Mg-Li-Al-Y-RE [34] and others. No data is available to date about the successful application of these alloys as a constructional material of endoprostheses. Apparently, these alloys have not also provided characteristics that are sufficient for successful performance by biosoluble stents their main medical function: to prevent repeated blocking (restenosis) of coronary vessel lumen after operation PTCA with a stenting.

An analysis of existing data shows that modern magnesium-based alloys have considerably different set of mechanical and corrosion properties. Some of them have higher strength and low-ductility, while others are less strong and a little more deformable. Nevertheless, even the peak-values one of mechanical properties (e.g. Yield stress (YS), ultimate tensile stress (UTS) and, especially, elongation up to rupture (δ)) for the best of known magnesium-based alloys, which are considered as potential material for endoprostheses, are far lower than those for stainless steel 316LVM (YS ~ 280 MPa, UTS ~ 400 MPa, δ ~ 40 %) that is one of widespread constructional materials of permanent stents. For example, on different data, extruded alloy AZ31, alloy LAE442, extruded alloy WE43 have elongation up to rupture about of 15 %, 18 % and 17 %, respectively.

respectively, at a level of YS over the ranges of 150-200 MPa and UTS of 250-270 MPa. Our researches of stent models made of alloys that we have developed [14, 33] and follow-up calculations have shown that construction material of stents based on magnesium alloy should have elongation up to rupture better than 23% and strength properties on a levels: YS >140 MPa and UTS >170 MPa.

It is known that alloying elements, their distribution as well as the composition of the chemical compounds that they form influences the resistance to corrosion of alloy. The corrosion rate of magnesium alloys depends also on a structural condition of alloy and methods of manufacturing it.

It is difficult to compare existing data on a corrosion rate of various magnesium alloys, even received in the identical type of tests (for example, seawater immersion test), because different methods calculation of a corrosion rate (a loss of weight, a hydrogen evolution etc.) have various measurement errors. Even the same author's data about a corrosion rate for the same alloys can differ. Witte [21] gives named data for alloys LAE442 and AZ91D. The measured corrosion rates were for these alloys, respectively: 6.9 mm/years and 2.8 mm/years (in electrochemical test) and 5.535 mm/years and - 0.267 mm/years (in immersion test). However, in any case, corrosion properties of modern magnesium-based alloys wish to be the better. At the same times, in our opinion, the necessary corrosion rate should be about of 0.05 mm/years ($\sim 0.025 \text{ mg/cm}^2/\text{day}$, at the specific density of Mg alloy $= 1.8 \text{ g/cm}^3$), if to assume that 100-mkm stent's strut should be dissolved in about 6 months.

Thus, properties of existing magnesium-based alloys, especially plasticity and resistance to corrosion *in vivo*, are poor for constructional material of biodegradable endoprosthesises, in particular, vessel stents.

So, it is desirable, for example, to develop magnesium-based alloys having yield stress at room temperature that is more than 140 MPa, ultimate tensile strength of more than 170 MPa, elongation up to rupture more than 23% and corrosion resistance in a simulated body fluid (SBF) better than $0.025 \text{ mg/cm}^2/\text{day}$. Besides, such alloys may not comprise harmful for living body impurities (such as Ag, Al, As, Be, Cd, Cr, Hg, Sr, Th, Zn etc.) in a concentration above than 0.0001 % by weight.

There is a need in the art for a magnesium alloy having parameters that will provide a biodegradable endoprosthesis that can perform its medical function efficiently for the duration of and within its expected lifespan. For example, medical stent may dissolve *in vivo* with such an even corrosion rate that will maintain the requisite scaffolding capability

over a period of time, which is necessary for treatment, and without premature mechanical failure due to loss of strength due to a decreased-thickness of strut.

THE SUMMARY OF THE INVENTION

5 The present invention provides a medical device, in particular, a biodegradable endoprosthesis body such as a vessel stent, formed at least partly from a constructional material comprising super-pure magnesium, or an alloy thereof further comprising one or more (other) super-pure alloying elements. The device of the invention being formed from the said constructional material has excellent formability at room temperature, an optimal
10 combination of strength, plasticity and corrosion resistance *in vivo* in the comparison with endoprostheses formed from known magnesium-based alloys. The high formability facilitates manufacture of the endoprosthesis body by usual methods of metal processing: extrusion, forging, rolling, drawing, machining job etc.

In one embodiment, the invention provides a medical biodegradable endoprosthesis body
15 formed at least partly from a constructional material comprising super-pure magnesium.

According to another embodiment, the invention provides a medical biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and one or more super-pure alloying elements.

According to one embodiment, the invention provides a biodegradable endoprosthesis
20 body formed at least partly from a constructional material consisting of super-pure magnesium, or from a constructional material consisting of an alloy of super-pure magnesium and one or more super-pure alloying elements. The limitations described throughout the application also apply to the aforementioned embodiment.

The endoprosthesis body is formed at least partly from the constructional material;
25 according to one embodiment, it is formed mostly, essentially or entirely therefrom.

The super-pure magnesium as used in the present invention preferably has a purity of not less than 99.998 % (w/w). Preferably, the super-pure magnesium contains a controlled content of each impurity in the group of iron, cobalt, nickel and copper equal to or less than 0.0002 % (w/w), preferably between 0.0002 % and 0 % (w/w), more preferably
30 between 0.0002 % and 0.000002 % (w/w). In other words, the impurity of super-pure magnesium contains 0.0002 % (w/w) or less iron, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w) iron; 0.0002 % (w/w) or less cobalt, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002

% and 0.000002 % (w/w) cobalt; 0.0002 % (w/w) or less nickel, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w) nickel; and 0.0002 % (w/w) or less copper, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w) copper. The level of purity or
5 impurity (% , w/w) is expressed as a percentage weight of the super-pure magnesium. The iron, cobalt, nickel and copper as used herein refer to the metal element.

The super-pure alloying element as used in the magnesium alloy described herein preferably has a purity of not less than 99.99 % (w/w). The super-pure alloying element as used in the magnesium alloy of the described herein preferably has a content of each
10 impurity in the group iron, cobalt, nickel and copper of not more than 0.00025 % (w/w), preferably between 0.00025 % and 0 % (w/w), preferably between 0.0002 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w).

In other words, the super-pure alloying element contains, as impurities, not more than 0.00025 % (w/w) iron, preferably between 0.00025 % and 0 % (w/w), preferably between
15 0.0002 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) iron; 0.0002 % (w/w) or less cobalt, preferably between 0.00025 % and 0 % (w/w), more preferably between 0.0002 % and 0.00002 % (w/w) cobalt; not more than 0.00025 % (w/w) nickel, preferably between 0.00025 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) nickel; and not more than 0.00025 % (w/w) copper,
20 preferably between 0.00025 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) copper. The level of purity (% , w/w) is expressed as a percentage weight of the super-pure alloying element.

When purity or impurity is mentioned, only metal components are considered, *i.e.* non-metallic constituents such as oxygen, hydrogen nitrogen etc, are not considered.

25 The one or more super-pure alloying elements is preferably chosen from indium, scandium, yttrium, gallium and rare earth elements (RE). Where more than one super-pure alloying element is present, two or more may be different REs.

Super-pure scandium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0.1 to 15 % (w/w alloy).

30 Super-pure yttrium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0.1 to 5 % (w/w alloy).

Super-pure gallium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0.1 to 5 % (w/w alloy).

Super-pure indium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0.1 to 5 % (w/w alloy).

A super-pure rare earth element as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0.1 to 5 % (w/w alloy). Where there
5 is more than one rare earth element, the total of rare earth elements present may be in a quantity of 0.1 to 5 % (w/w alloy).

According to another embodiment, the invention provides an endoprosthesis body formed at least partly from the constructional material defined herein.

The present invention also relates to a biodegradable endoprosthesis body such as a
10 screw, bolt, plate, staple, tubular mesh, stent, spiral, coil, wire, marker and catheter formed at least partly from the constructional material of the invention.

The present invention also relates to a use of a constructional material according to the invention for the manufacture of a biodegradable endoprosthesis such as a screw, bolt, plate, staple, tubular mesh, stent, spiral, wire, coil, marker and catheter. Such devices are
15 commonly known as an endoprosthesis body or implant.

DETAILED DESCRIPTION OF THE INVENTION

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art. All publications referenced
20 herein are incorporated by reference thereto. All United States patents and patent applications referenced herein are incorporated by reference herein in their entirety. The designation of numerical ranges by endpoints includes all integer numbers and, where appropriate, fractions subsumed within that range (*e.g.* 1 to 5 can include 1, 2, 3, 4 when referring to, for example, a number of items, and can also include 1.5, 2, 2.75 and 3.80,
25 when referring to, for example, concentration). The designation of end points also includes the end point values themselves (*e.g.* from 1.0 to 5.0 includes both 1.0 and 5.0). Unless otherwise stated, all percentages, when expressing a quantity, are weight percentages. Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the
30 embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined

in any suitable manner, as would be apparent to a person skilled in the art from this disclosure, in one or more embodiments. Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the appended claims, any of the claimed embodiments can be used in any combination.

The present invention relates to a finding by the inventors that a constructional material for a biodegradable endoprosthesis comprising super-pure magnesium or an alloy comprising super-pure magnesium and one or more super-pure alloying elements provides requisite properties such as yield stress, tensile strength, elongation up to rupture at a level that ensures an endoprosthesis formed therefrom is capable of maintaining its medical function for the duration of its expected life span.

Biodegradability degree of the endoprosthesis is determined by the rate of corrosion *in vivo* of the constructional material. The inventors have found out that the very weak or absent dependence of corrosion rate of magnesium on iron concentration over the range below 0.001% that has been stated in the art does not answer to validity. The inventors have found that, contrary to understanding of the art, further increase of magnesium purity from 99.99 % (high pure) to 99.998 % (super-pure), when there is a simultaneous decrease of iron, nickel and copper content in magnesium far lower than 0.001 %, results in an additional reduction of the corrosion rate in an aqueous solution of sodium chloride by three-four times. Besides, corrosion of super-pure material is homogenous throughout its surface and a pitting corrosion is absent.

Due to absence of pitting corrosion, a biodegradable endoprosthesis body such as a stent formed from the super-pure constructional material corrodes more evenly, maintaining its integrity for the full duration of treatment. Restenosis and inflammation are decreased, because the formation of large stent fragments - released when localized corrosion breaks up the stent into large sections still mainly uncorroded - is avoided. As a consequence of homogenous corrosion, strut thickness can be reduced, for example, from 170 microns used in the art, for example, to, for example, 90 microns, without a risk of premature loss of stent integrity. In the art, a reduction in corrosion is typically achieved using a hydrophobic coating, which adds to the costs of stent manufacture, and requires compatibility with any additional (e.g. drug) coating.

Concomitantly, the period to the full dissolution of endoprosthesis is increased three-four fold, and a quantity of evolved hydrogen per time unit is reduced also. This favorably affects a reaction of a living body towards endoprosthesis introduction.

Moreover, such low levels of undesirable impurities strongly change not only corrosion rate and a degree of homogeneity of corrosion, but even the composition of corrosion product of the explored magnesium materials is changed: instead of usual floccus products of dissociation (hydroxides, chlorides) the inventors observed a firm surface layer. This layer is protective and additionally lowers corrosion rate. The X-ray diffraction analysis has shown presence in this layer of the new compound, which was not observed earlier in earlier studies of corrosion of magnesium materials. This new compound has rhombic lattice having parameters $a=5.864\text{\AA}$, $b=2.353\text{\AA}$, $c=4.206\text{\AA}$.

One embodiment of the invention provides a medical biodegradable endoprosthesis body, formed at least partly from a constructional material comprising super-pure magnesium.

One embodiment of the invention provides a medical biodegradable endoprosthesis body, formed at least partly from a constructional material comprising an alloy of super-pure magnesium and one or more super-pure alloying elements.

Another embodiment of the invention provides a method for manufacture of a constructional material for a medical biodegradable endoprosthesis body, comprising the step of combining super-pure magnesium and one or more super-pure alloying elements to form an alloy.

The super-pure magnesium as used in the present invention preferably has a purity of not less than 99.998 % (w/w). The purity refers to quantity of magnesium compared with the total metal content of the super-pure magnesium. Preferably, the super-pure magnesium has a controlled content of each impurity in the group of iron, cobalt, nickel and copper, equal to or less than 0.0002% (w/w), preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w). In other words, the super-pure magnesium contains, as impurities, 0.0002 % (w/w) or less iron, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w) iron; 0.0002 % (w/w) or less cobalt, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w) cobalt; 0.0002 % (w/w) or less nickel, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w) nickel; and 0.0002 % (w/w) or less copper, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.000002 % (w/w)

copper. Besides, such super-pure magnesium may not comprise impurities harmful for the living (e.g. human or animal) body such as Ag, Al, As, Be, Cd, Cr, Hg, Sr, Th, Zn etc. in a concentration above than 0.0001 % (w/w). The impurity refers to the quantity of metal impurity compared with the total metal content of the super-pure magnesium. Preferably, the super-pure magnesium has both the above-specified purity and impurity levels.

Each and every super-pure alloying element present in the alloy preferably has a purity of not less than 99.99 % (w/w). The purity refers to the quantity of alloying element compared with the total metal content of the super-pure alloying element. Preferably, each and every super-pure alloying element has a content of each impurity from the group iron, cobalt, nickel and copper, of not more than 0.00025 % (w/w), preferably between 0.00025 % and 0.00002 % (w/w).

In other words, the impurity in the super-pure alloying element comprises not more than 0.00025 % (w/w) iron, preferably between 0.00025 % and 0 % (w/w), preferably between 0.0002 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) iron, 0.0002 % (w/w) or less; cobalt, preferably between 0.00025 % and 0 % (w/w), preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % and 0.00002 % (w/w) cobalt; not more than 0.00025 % (w/w) nickel, preferably between 0.00025 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) nickel and not more than 0.00025 % (w/w); copper, preferably between 0.00025 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) copper. The impurity refers to the quantity of metal impurity compared with the total metal content of the super-pure alloying element in question. Thus, when purity or impurity is mentioned, only metals are considered; non-metallic constituents such as oxygen, hydrogen, nitrogen etc, are not considered. Besides, each super-pure alloying element may not comprise impurities harmful for the living (e.g. human or animal) body such as Ag, Al, As, Be, Cd, Cr, Hg, Sr, Th, Zn etc. in a concentration above than 0.0005 % (w/w). The impurity refers to the quantity of metal impurity compared with the total metal content of the super-pure alloying element. Preferably, the super-pure magnesium has both the above-specified purity and impurity levels.

In another embodiment, the invention provides a biodegradable endoprosthesis formed from a constructional material comprising an alloy of super-pure magnesium and one or more super-pure alloying elements, wherein the one or more super-pure alloying elements is preferably chosen from indium, scandium, yttrium, gallium or rare earth elements (RE). In another embodiment, the invention provides a method for the manufacture of the constructional material for a biodegradable endoprosthesis, wherein the one or more

super-pure alloying elements is preferably chosen from indium, scandium, yttrium, gallium and rare earth elements (RE). Where more than one super-pure alloying element is present, two or more may be REs. The number of super-pure alloying elements in the alloy may be 1, 2, 3, 4, 5, 6 or more.

- 5 Super-pure scandium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity equal to 0, 0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5, 14, 14.5 or 15 % (w/w alloy) or a value in the range between any two of the aforementioned values, preferably between 0.1 and 15 %, more preferably between 0.1 and 5 %. According to
10 various data, scandium has a limit of solubility in magnesium up to 28 %. The addition of scandium to magnesium within the limits up to 15 % provides creation of Mg-Sc solid solution after homogenization of the ingot. It increases plasticity and strength of the alloy and slightly increases corrosion rate in the sodium chloride solution (at scandium content more than 5 %). Scandium is also good modifier of grain structure of magnesium ingots.
15 Scandium additions to magnesium-based alloys improve foundry characteristics, corrosion resistance and/or mechanical strengths.

- Super-pure yttrium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0, 0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 % (w/w alloy) or a value in the range between any two of the aforementioned values. Preferably it
20 is present in a quantity between 0.1 and 5.0 % (w/w alloy). Yttrium has the limit of solubility in magnesium of about 2 to 6 % at room temperature. The addition up to 4 % of yttrium to magnesium increases its strength without essential reduction in plasticity and in corrosion resistance of Mg-Y alloy. Yttrium may also influence the suppression of smooth muscles cell proliferation (restenosis prevention), etc, thereby providing a therapeutic
25 function suitable for vascular prosthesis such as a stent.

- Super-pure indium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0, 0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 % (w/w alloy) or a value in the range between any two of the aforementioned values. Preferably, it
30 is present in a quantity between 0.1 and 5.0 % (w/w alloy). Research by the inventors on the multi-component magnesium alloys has revealed an additional benefit of super-pure indium. For instance, addition of super-pure indium to a Mg-Sc-Y-RE-Zr alloy system, leads to an abrupt grain refinement during crystallization thereof due to creation of inter-metallic phases between scandium, yttrium and indium. The semi-finished products containing indium so formed after extrusion, blacksmithing or equal-channel angular
35 extrusion possess a unique characteristic for magnesium alloys formability. At room

temperature the alloy can withstand, without fracture, deformations up to 90 % by drawing (some passes), and up to 30 % by rolling (per one pass) without intermediate annealings. Such a high deformability is so far only known for some binary alloys Mg-Li.

Corrosion test (immersion) has shown that an additional benefit of indium when added to an alloy of the system Mg-Sc-Y-RE; it leads to reduction of the corrosion rate.

As far as medical applications are concerned, the present alloys may be used safely, for example in implants such as stents or staples. Data regarding toxicity and common influence of indium chemical compounds on humans indicate it is safe. Indium is included in the FDA's GRAS list (Generally Recognized as Safe).

According to one embodiment of the invention, indium can be replaced in the same quantity (w/w) with gallium that offers similar influence on properties in the alloy. Alternatively, alloying of magnesium with indium and gallium is also possible.

Super-pure gallium as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0, 0.1, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 % (w/w alloy) or a value in the range between any two of the aforementioned values. Preferably it is between 0.1 and 5.0 % (w/w alloy). Indium can be replaced in the same quantity (w/w) with gallium that offers similar influence on properties in the alloy. Alternatively, alloying of magnesium with a mixture of indium and gallium is also within the scope of the invention, in which case, the indium and gallium may be present in a quantity of 0, 0.1, 0.5, 1.0, 1.5, 2.0, 2.5, 3, 3.5, 4.0, 4.5, 5.0 % (w/w alloy) or a value in the range between any two of the aforementioned values. Preferably, it is between 0.1 and 5.0 % (w/w alloy).

A super-pure rare earth element (RE) as the sole or one of several (*i.e.* two or more) super-pure alloying elements may be present in a quantity of 0, 0.1, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 % (w/w alloy) or a value in the range between any two of the aforementioned values. Preferably it is between 0.1 and 5.0 % (w/w alloy). Where there is more than one rare earth element, the total of rare earth elements present may be in a quantity 0, 0.1, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 % (w/w alloy) or a value in the range between any two of the aforementioned values, preferably between 0 and 5.0 % (w/w alloy). The RE is preferable chosen from the Lanthanide Series (*i.e.* Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb) or Lutetium (Lu)). The influence of rare earth elements on properties of magnesium alloys depends on their solubility in magnesium

alloys and their melting point. Solubility of RE in solid magnesium ranges from practically zero (La) up to 7 percent (Lu). Metals from group with nuclear numbers from 64 (Gd) up to 71 (Lu) have melting temperatures and limits of solubility in magnesium higher than metals of cerium group. Alloying up to 5 % RE with magnesium raises strength and corrosion resistance of alloy. Besides, rare earth metals reduce micro-porosity of magnesium alloys during production of an initial ingot.

The concentration range of each super-pure alloying element has been specified over the above range of concentrations, which optionally includes 0 %. This designates that the indicated alloying element may be absent from the material so formed. In the case of a single-component material, the proposed constructional material would contain only super-pure magnesium.

The alloy contained in the endoprosthesis has an improved combination of strength, plasticity and high corrosion resistance in body liquids, high formability at ambient temperature in comparison with existing magnesium alloys. The high formability allows certain forms to be made by usual methods of metals processing - extrusion, forging, rolling, drawing, machining job etc.

The constructional material may comprise super-pure magnesium (Mg) or an alloy thereof with one or more super-pure alloying elements (Sc, Y, In, Ga, RE) in the following combinations:

- Single-component material: super-pure magnesium.
- Two-component alloy: Mg-Sc, Mg-Y, Mg-In, Mg-Ga, or Mg-RE.
- Three-component alloy: Mg-Sc-Y, Mg-Sc-In, Mg-Sc-Ga, Mg-Sc-RE, Mg-Y-In, Mg-Y-Ga, Mg-Y-RE, Mg-In-Ga, Mg-In-RE, or Mg-Ga-RE.
- Four-component alloy: Mg-Sc-Y-In, Mg-Sc-Y-Ga, Mg-Sc-Y-RE, Mg-Sc-In-Ga, Mg-Sc-In-RE, Mg-Sc-Ga-RE, Mg-Y-In-Ga, Mg-Y-In-RE, Mg-Y-Ga-RE, or Mg-In-Ga-RE.
- Five-component alloy: Mg-Sc-Y-In-Ga, Mg-Sc-Y-In-RE, Mg-Sc-Y-Ga-RE, Mg-Sc-In-Ga-RE, or Mg-Y-In-Ga-RE.
- Six-component alloy: Mg-Sc-Y-In-Ga-RE.

According to one aspect of the invention, biodegradable endoprosthesis body is at least partly formed from a constructional material comprising super-pure magnesium. According to another aspect of the invention, biodegradable endoprosthesis body is at least partly formed from a constructional material comprising an alloy of Mg-Sc, Mg-Y, Mg-Sc-In, Mg-Sc-Y, Mg-Sc-Y-In, or Mg-Sc-Y-In-RE.

A general increase of magnesium purity (and of the alloying elements) results in improvement of plastic properties e.g. elongation up to rupture, formability, and in some reduction in strength properties (YS, UTS). The strength and plasticity of a metal sharply rises, when a grain size of the metal is reduced. The relationship between the flow stress
5 (σ) and the grain size (d) is defined by the equation of Hall - Petch - Stroh:

$$\sigma = \sigma(0) + k / \sqrt{d}, \quad (1)$$

(wherein, $\sigma(0)$ and k are constant).

Other things being equal, the strength of a metal material increases in inverse proportion to the square root of the grain size. There is not strong dependence of plasticity on grain
10 size of metal, but it is the fact that it increases with decreasing of grain size. An increasing ratio depends on operating mechanism of plastic deformation.

Usual (industrial) methods of deformation processing of metals allow a grain size not less than 10-20 micrometers to be achieved; this may not be sufficient for essential increase of their strength and plastic characteristics. It is known that metallic materials with the ultra
15 fine-grained structure (UFG) show higher level of mechanical characteristics and have higher deformability. However, it is often difficult to create such structures in materials having low plasticity in initial conditions (for example, in ingots).

According to one embodiment of the invention, the biodegradable endoprosthesis is at least partly formed from a constructional material, that has the grain size of less than 5
20 microns and comprising super-pure magnesium or alloy of super-pure magnesium and super-pure alloying elements,.

The present inventors have found that the UFG structure with the grain size of 0.1 - 3.0 microns can be achieved by a method of intensive deformation that comprises repeated alternation of a straight-through extrusion and a settlement (it gives a high component of
25 shear stress during a deformation) in a complex with the programmed heat treatment for such non-conventional materials as beryllium and niobium-titanium super-conducting alloys. The inventors found that the strength is increased by 30 % and plasticity many times [35]. It is also possible to use an intensive deformation, *i.e.* changing of materials' flow direction for the creation of shear stress, during the processing of materials. Then
30 the developed method of intensive deformation has been applied to magnesium and its alloys.

For additional improvement in the combination of mechanical and corrosion characteristics of the present alloys, the alloy of invention may be used in ultra fine-grained (UFG) condition with a grain size of 5 microns or less. The UFG structure is

created in preliminary forged (extruded) ingots by methods of programmed intensive plastic deformation in combination with programmed heat treatment.

Further setting up of any necessary product form (for practical using) can be made according to any known technological schemes: rolling, extrusion, press forming etc.

- 5 The super-pure magnesium (Mg) and each super-pure alloying element (alloying element *i.e.* scandium, yttrium, indium, gallium, or RE) that were used for preparation of the constructional material of present invention have a purity much higher than that for commercially pure elements. The inventors have produced the super-pure magnesium and necessary components of the alloy thereof contained in the endoprosthesis body by a
10 combination known methods to refine each metal, namely multi-stage vacuum distillation using a condenser with a gradient of temperature as described by Ivanov *et al* [36]. The purification method has been described in the Patent US 5 698 158 [37] provides an uncertain content of zinc in purified magnesium. We consider this element as undesirable in applications of magnesium and its alloys as constructional material of medical
15 biosoluble endoprosthesis. Zinc is included, for example, into the first ten of heavy metals, which content is limited in foodstuff.

Content of each impurity in the constructional material of biodegradable endoprosthesis was measured by method laser mass-spectrometry (EMAL-2) with double focusing by the method Mattauch-Gerzog [38]. The sensitivity of the said instrument of high precision is
20 about 1×10^{-6} % w/w for any element having an atomic number of more than 3.

The alloy for the constructional material of a biodegradable endoprosthesis is prepared using the known methods for the preparation of ingot of magnesium-based alloys as described, for example, by Lipnitsky and Morozov [39]. Generally, the said alloy is prepared by the direct fusion of super-pure magnesium with the specified elements in a
25 high-frequency induction furnace having an atmosphere of high purity argon and in a high purity graphite crucible. For full dissolution of all components, the alloy is stood in the crucible at the temperature of 700, 710, 720, 730, 740, 750, 760, 770, 780, 790, 800, 810, 820, or 830 degree Celsius or a temperature in a range between any two of the aforementioned values, preferably between 760 to 780 degree Celsius.

- 30 The super-pure magnesium or super-pure alloy thereof as defined herein is suitable for use in any biodegradable medical device, including an endoprosthesis body or endoprosthesis, which has contact with a living body fluid and/or tissue *in situ*. An example of an endoprosthesis body includes a screw, bolt, plate, staple, tubular mesh, stent, spiral, coil, wire, marker or catheter. Such endoprosthesis bodies are well known in

the art. Where the endoprosthesis body is a stent, for example, it may be a cylinder which that is perforated with passages that are slots, ovoid, circular, regular, irregular or the like shape. It may also be composed of helically wound or serpentine wire structure in which the spaces between the wires form the passages. A stent may also be flat perforated structure that is subsequently rolled to form a tubular structure or cylindrical structure that is woven, wrapped, drilled, etched or cut to form passages. Such cylinder or wires may be formed from the structural material defined herein. A stent may also be combined with a graft to form a composite medical device, often referred to as a stent graft. A stent may capable of being coated with a composition. The endoprosthesis body may be implantable. One embodiment of the invention is an endoprosthesis body formed at least partly from the super-pure constructional material defined herein. It will be understood that the endoprosthesis body defined herein inevitably contains the super-pure constructional material.

The inventors, on the basis of the existing references and their own research, have chosen as preferable embodiments an endoprosthesis body at least partly formed from the described constructional material that has the optimal combination of mechanical and corrosion characteristics at the room temperature (among the known magnesium-based alloys).

SOME PREFERRED EMBODIMENTS

According to one embodiment, the invention provides a biodegradable endoprosthesis body formed at least partly from a constructional material comprising super-pure magnesium, or from a constructional material comprising an alloy of super-pure magnesium and one or more super-pure alloying elements.

According to one embodiment, the invention provides a biodegradable endoprosthesis body formed at least partly from a constructional material consisting of super-pure magnesium, or from a constructional material consisting of an alloy of super-pure magnesium and one or more super-pure alloying elements. The limitations described throughout the application also apply to the aforementioned embodiment.

According to another embodiment, the invention provides a biodegradable endoprosthesis body formed at least partly from a constructional material comprising super-pure magnesium or alloy thereof further comprising one or more super-pure alloying elements, wherein said super-pure magnesium has a purity of not less than 99.998 % (w/w), or wherein the super-pure magnesium contains an impurity in the group iron, cobalt, nickel

and copper in a quantity of equal to or less than 0.0002 %, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % to 0.000002 % (w/w) of each said impurity.

According to another embodiment, the invention provides a biodegradable endoprosthesis body formed at least partly from a constructional material comprising super-pure magnesium or alloy thereof further comprising one or more super-pure alloying elements, wherein said super-pure magnesium has a purity of not less than 99.998 % (w/w), and wherein the super-pure magnesium contains an impurity in the group iron, cobalt, nickel and copper in a quantity of equal to or less than 0.0002 %, preferably between 0.0002 % and 0 % (w/w), more preferably between 0.0002 % to 0.000002 % (w/w) of each said impurity.

According to another embodiment, each and every super-pure alloying element forming the aforementioned alloys has a purity of not less than 99.99 % (w/w) and contains an impurity in the group iron, cobalt, nickel and copper in a quantity of no more than 0.00025 % (w/w), preferably between 0.00025 % and 0 % (w/w), more preferably between 0.00025 % and 0.00002 % (w/w) of each said impurity.

According to another embodiment, the invention provides a medical biodegradable endoprosthesis body, formed at least partly from a constructional material comprising super-pure magnesium, or an alloy thereof further comprising one or more super-pure alloying elements, wherein

- the super-pure magnesium has a purity of not less than 99.998 % (w/w) and contains a level of impurity of iron, cobalt, nickel and copper, each equal to or less than 0.0002 % (w/w) of each said impurity;
- one or more super-pure alloying elements each has a purity not lower than 99.99 % (w/w) and each contains impurity of iron, cobalt, nickel and copper at a level of no more than 0.00025 % (w/w) of each said impurity.

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and one or more super-pure alloying elements, wherein the one or more super-pure alloying elements are chosen from indium, scandium, yttrium, gallium and one or more rare earth elements (RE).

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an

alloy of super-pure magnesium and super-pure scandium, wherein the content of super-pure scandium in the alloy is between 0.1 to 15 % (w/w).

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and super-pure yttrium, wherein the content of super-pure yttrium in the alloy is between 0.1 and 5 % (w/w).

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and super-pure indium, wherein the content of super-pure indium in the alloy is between 0.1 and 5 % (w/w).

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and super-pure gallium, wherein the content of super-pure gallium in the alloy is between 0.1 and 5 % (w/w).

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and super-pure gallium and super-pure indium, wherein the content of super-pure gallium and super pure indium combined in the alloy is between 0.1 and 5 % (w/w).

According to another embodiment, the invention provides the biodegradable endoprosthesis body formed at least partly from a constructional material comprising an alloy of super-pure magnesium and one or more super-pure rare earth elements (RE), wherein the content of super-pure rare earth elements (RE) in the alloy is between 0.1 and 5 % (w/w).

According to another embodiment, the invention provides the biodegradable endoprosthesis body as described above, wherein the constructional material has a grain size of less than 5 microns.

According to another embodiment, the invention provides medical biodegradable endoprosthesis body, formed at least partly from the constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is medical stent. Another

embodiment of the invention is a medical stent formed at least partly from the constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named medical stent is a platform for drug-eluting stent.

5 Another embodiment of the invention is a drug-eluting medical stent formed at least partly from the constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is a medical staple. Another embodiment of the invention is a medical staple formed at least partly from the
10 constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is medical bolt. Another embodiment of the invention is a medical bolt formed at least partly from the constructional material as defined herein.

15 According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is medical plate. Another embodiment of the invention is a medical plate formed at least partly from the constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable
20 endoprosthesis body, wherein the named endoprosthesis is medical coil. Another embodiment of the invention is a medical coil formed at least partly from the constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is medical X-ray marker.
25 Another embodiment of the invention is a medical X-ray marker formed at least partly from the constructional material as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is medical catheter. Another embodiment of the invention is a medical catheter formed at least partly from the
30 constructional material of the invention. Another embodiment of the invention is a medical catheter formed from or comprising the construction material of the invention.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named endoprosthesis is medical screw, tubular mesh,

wire or spiral. Another embodiment of the invention is a medical screw, tubular mesh, wire or spiral formed at least partly from the constructional material of the invention.

According to another embodiment, the invention provides a use of a constructional material as defined herein, for the manufacture of an endoprosthesis body as defined herein.

According to another embodiment, the invention provides the biodegradable endoprosthesis body, wherein the named super-pure constructional material is, at least, a part of biocorrosible endoprosthesis body. Another embodiment of the invention is a biodegradable endoprosthesis body formed at least partly from the super-pure constructional material of the invention.

The endoprosthesis body described is formed at least partly from the constructional material; according to one embodiment, it may be formed mostly, essentially or entirely therefrom.

Another embodiment of the invention is a use of the constructional material as defined herein, for the manufacture of an endoprosthesis body as defined herein.

Another embodiment of the invention is a constructional material as defined herein i.e. comprising super-pure magnesium, or comprising an alloy of super-pure magnesium and one or more super-pure alloying elements.

EXAMPLES

Example 1

On available data, researchers have distinguished three grades of magnesium: low pure (LP) (~99.9 % Mg), commercially pure (CP) (~99.95 % Mg) and high pure (HP) (~99.98 % Mg). Content of iron, copper and nickel is restricted by the following limits (Table 1):

Table 1. The terminal concentrations of iron, copper, cobalt and nickel for different grades of magnesium.

Grade of Mg	Total purity of Mg, % wt.	Content, % wt.			
		Fe	Co	Cu	Ni
LP (low pure)	~ 99.9	0.028	-	0.001	0.002
CP	~ 99.95	0.020	-	0.002	0.002

(commercial pure or pure)					
HP (high pure)	~ 99.98	0.004	-	0.002	0.0009
SP (super pure; used in the invention)	> 99.998	< 0.0002	< 0.00002	< 0.0002	< 0.0002

We have carried out a purification of magnesium up to the purity of 99.998 % and more (only metal impurities are taken into consideration) by the way of double (triple) distillation in ultra-high vacuum. Such processing of commercially pure magnesium has resulted in decrease concentrations of adverse for corrosion resistance impurities (iron, nickel and copper) to a level equal to or below of 0.0002 % by weight and less for each specified impurity. Content of cobalt was reduced down to 0.00002 % w/w.

The specified content of iron, nickel and copper has resulted in essential improving of corrosion resistance of super-pure (SP) magnesium in comparison with CP and HP magnesium. The measured corrosion rates of the named grades of magnesium (immersion test, 0.9 % water solution NaCl, the method of weight loss measurement) were: CP Mg - 50 mg/cm²/day, HP Mg - 2 mg/cm²/day, SP Mg (used in the invention) - less than 0.01 mg/cm²/day.

The further purification of magnesium up to iron, cobalt, nickel and copper content down to a level about 0.00002 % (w/w) led to additional lowering of corrosion rate, and the obtained level (less than 0.005 mg/cm²/day) for such material is lower than that is necessary for practical purposes. Moreover, when the levels of undesirable impurities are 0.0002 % (w/w) and lower, they strongly change not only corrosion rate and a degree of homogeneity of corrosion, but even the composition of corrosion product of the explored magnesium materials is changed: instead of usual floccus products of dissociation (hydrochlorides) we observed the firm layer on their surface. This layer is protective and additionally lowers corrosion rate. The X-ray diffraction analysis has shown presence in this layer of the new compound, which was not observed in earlier studies of corrosion of magnesium materials. This new compound has rhombic lattice having parameters **a**=5.864Å, **b**=2.353Å, **c**=4.206 Å. The preferred concentrations of iron, cobalt, nickel and copper for magnesium and its alloys may be on the level of about 0.0002 to 0.000002 % (w/w) each by weight. This will ensure an optimal corrosion rate of biodegradable endoprostheses and necessary uniformity of corrosion process. At the same time,

uniformity of corrosion may be a relevant parameter too, because, even at low common level of corrosion rate, overetching (due to a pitting corrosion) of some struts, for example, leads to a loss of stent integrity and of possibility to provide scaffold function.

To keep a low content of undesirable impurities in the alloy comprising super-pure magnesium described herein, the inventors have used for the alloy material, alloying components that were also super-pure (99.99 % w/w or better). They have prepared necessary alloying elements containing in each of them no more than 0.00025 % of each impurity in the group: iron, cobalt, nickel and copper.

In spite of the fact that all alloying elements used by the inventors are more noble concerning magnesium (on hydrogen potential) and, therefore, would be expected to raise the corrosion rate of the alloy so formed, the inventors have found out that, contrary to expectation, an appreciable increase of corrosion rate of an alloy as described herein has not occurred: the corrosion rate was about 0.020 mg/cm²/day.

The influence of alloying elements on the mechanical and corrosion properties of magnesium alloys was well studied for binary systems, but in multi-component alloy their mutual and aggregate influence can turn out to be complex and unpredictable. Therefore, the choice of the basic alloying elements and their interrelations in an alloy are the controlling factor for its future properties.

The inventors, when considering the alloying elements, discriminate the group of rare-earth elements (RE) - elements with numbers from 57 up to 71 in the Periodic table - from both yttrium and scandium. Though yttrium and scandium have an external electronic shell structure that is identical to RE, and a similarity with some of the chemical properties of RE, they would be expected to differ from RE in alloy compositions, according to ASTM standard, because they differ in an influence on alloys properties.

Basic alloying elements for the magnesium-based alloys used in the endoprosthesis body of the invention, namely; indium, gallium, scandium, yttrium and RE, provide alloys with favorable characteristics (for example, plasticity) and yet do not change essentially other characteristics (for example, resistance to corrosion). Alloys of the invention contain alloying elements in the quantities that far less their solubility in magnesium. It is desirable also not to have in an alloy composition such elements that have a negative influence on a living body. This requirement is met by the high general purity of offered alloys.

Example 2

Ingots of super-pure magnesium (99.999 % magnesium, content of iron, copper and nickel is about of 0.00016 %, by weight, of each; content of cobalt was less than of 0.00001 % w/w) was extruded from diameter of 50 mm to diameter of 30 at the temperature of 290°C.

5 Then the obtained semi-finished product was subjected to deformation by equal-channel angular extrusion at the temperature of 270-240°C, number of cycles of extrusion - 6, with intermediate annealing at the temperature of 280°C through 2 - 3 cycles. Samples were cut out from the obtained extrudate for the tensile test at room temperature and tests for corrosion (in 0.9 % sodium chloride water solution).

Test results 2

10 Mechanical properties (after annealing at the temperature of 150°C within one hour): YS=142 MPa, UTS=165 MPa, elongation=28 %.

The corrosion rate (calculated from a weight loss of specimens and by quantitative definition of the magnesium, which has passed in the solution, through the fixed time intervals): 0.008 mg/cm²/day.

15 Results of tests show that this material of the invention has the best of known corrosion properties in comparison with the widespread industrial alloys of magnesium.

Example 3

20 An alloy contained essentially of magnesium with purity of 99.998 % with addition of (% by weight) 8 % scandium and 2.7 % yttrium. Contents iron, nickel and copper in the alloy did not exceed 0.00024 % of each, and contents of incidental elements and impurities did not exceed 0.0002 %. The alloy was made by a way of the direct fusion of magnesium with the preliminary prepared master alloy with the specified elements in a high-frequency induction furnace having an atmosphere of high purity argon and in a high purity graphite crucible.

25 For full dissolution of alloying components, the alloy was stood in the crucible at the temperature of 770°C within 30 minutes and then was poured out into a cooled steel mold with a special daubing by method of bottom teem.

30 The obtained ingot was extruded from diameter of 50 mm to diameter of 30 mm at a temperature of 360°C. Then the obtained semi-finished product was subjected to deformation by equal-channel angular extrusion at the temperature of 350-320°C, number of cycles of extrusion 8, with intermediate annealing at the temperature of 360°C through 2 - 3 cycles (at achievement of micro-hardness H_μ of 90 kg/mm²).

35 Samples were cut out from the obtained extrudate for the tensile test at room temperature and tests for corrosion (in 0.9 % sodium chloride water solution).

Test results 3

Mechanical properties (after annealing at the temperature of 460°C within one hour):
YS=150 MPa, UTS=175 MPa, elongation=23 %.

The corrosion rate (calculated as in the example 1): 0.022 mg/cm²/day.

- 5 Results of tests show that this alloy has the optimal combination of mechanical and corrosion properties in comparison with the widespread industrial alloys of magnesium.

Example 4

- 10 An alloy containing essentially magnesium with purity of 99.998 % with addition of (% by weight) 3 % scandium, 4 % yttrium and 2 % indium. Contents iron, cobalt, nickel and copper in the alloy did not exceed 0.00022 % of each, and contents of incidental elements and impurities did not exceed 0.0002 %.

Ingot was prepared as in example 2.

- 15 The obtained ingot was extruded from a diameter of 50 mm to diameter of 30 mm at a temperature of 370°C. Then the obtained semi-finished product was subjected to deformation by equal-channel angular extrusion at the temperature of 350-330°C, number of cycles of extrusion was 8, with intermediate annealing at the temperature of 360°C through 2 - 3 cycles (at achievement of micro-hardness H μ of 95 kg/mm²).

Samples have been cut out from the obtained extrudate for the tensile test at room temperature and tests for corrosion.

20 Test results 4

Mechanical properties (after annealing at the temperature of 460°C within one hour):
YS=165 MPa, UTS=195 MPa, elongation=25 %.

The corrosion rate (calculated as in the example 1): 0.02 mg/cm²/day.

- 25 Results of tests show that this alloy has the optimal combination of mechanical and corrosion properties in comparison with the widespread industrial alloys of magnesium.

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CLAIMS

1. A medical biodegradable endoprosthesis body, formed at least partly from a constructional material comprising super-pure magnesium, or an alloy thereof further comprising one or more super-pure alloying elements, wherein
 - 5 - the super-pure magnesium has a purity of not less than 99.998 % (w/w) and contains a level of impurity of iron, cobalt, nickel and copper, each equal to or less than 0.0002 % (w/w) of each said impurity;
 - one or more super-pure alloying elements each has a purity not lower than 99.99 % (w/w) and each contains impurity of iron, cobalt, nickel and copper at a level of no
10 more than 0.00025 % (w/w) of each said impurity.
2. The endoprosthesis body according to claim 1, wherein the one or more super-pure alloying elements is chosen from scandium, yttrium, indium, gallium or one or more rare earth elements (RE).
3. The endoprosthesis body according to claim 2, wherein a content of super-pure
15 scandium in the alloy is between 0.1 and 15 % (w/w).
4. The endoprosthesis body according to claim 2 or 3, wherein a content of super-pure yttrium in the alloy is between 0.1 and 5 % (w/w).
5. The endoprosthesis body according to any of claims 2 to 4, wherein a content of super-pure indium in the alloy is between 0.1 and 5 % (w/w).
- 20 6. The endoprosthesis body according to any of claims 2 to 5, wherein a content of super-pure gallium in the alloy is between 0.1 and 5 % (w/w).
7. The endoprosthesis body according to any of claims 2 to 6, wherein a content of one or more super-pure RE in the alloy is between 0.1 and 5% (w/w).
8. The endoprosthesis body according to any of claims 1 to 7, wherein the constructional
25 material has a grain size of less than 5 microns.
9. The endoprosthesis body according to any of claims 1 to 8, which is a medical stent.
10. The endoprosthesis body according to any of claims 1 to 8, which is a drug-eluting medical stent.
11. The endoprosthesis body according to any of claims 1 to 8, which is a medical staple.
- 30 12. The endoprosthesis body according to any of claims 1 to 8, which is a medical bolt.
13. The endoprosthesis body according to any of claims 1 to 8, which is a medical plate.

14. The endoprosthesis body according to any of claims 1 to 8, which is a medical coil.
15. The endoprosthesis body according to any of claims 1 to 8, which is an X-ray marker.
16. The endoprosthesis body according to any of claims 1 to 8, which is a medical catheter.
- 5 17. The endoprosthesis body according to any of claims 1 to 8, which is a medical screw, tubular mesh, wire or spiral.
18. Use of a constructional material as defined in any of claims 1 to 8, for the manufacture of an endoprosthesis body as defined in any of claims 9 to 17.
19. A constructional material comprising super-pure magnesium, or an alloy thereof
10 further comprising one or more super-pure alloying elements as defined in any of claims 1 to 8.
20. A method for the manufacture of a constructional material for a medical biodegradable endoprosthesis body, comprising the step of combining super-pure magnesium as defined in claim 1, and one or more super-pure alloying elements as defined in any
15 of claims 1 or 2 to form an alloy.
21. Method according to claim 20, wherein the one or more super-pure alloying elements are combined in the alloy in the quantity defined in any of claims 3 to 7.