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# MAGNESIUM-ZINC-CALCIUM ALLOY, METHOD FOR PRODUCTION THEREOF, AND USE THEREOF

This patent application relates to a magnesium alloy and to a method for the production thereof and to the use thereof.

It is known that the properties of magnesium alloys are decisively defined by the type and quantity of the alloying elements and impurities as well as the production conditions. The effects of the alloying elements and impurities on the properties of the magnesium alloys have been long known to a person skilled in the art and illustrate the complex nature of determining the properties of binary or ternary magnesium alloys for the use thereof as implant materials.

The alloying element used most frequently for magnesium is aluminum, resulting in increased tensile strength due to solid solution and precipitation hardening and fine grain formation, but also in microporosity. Moreover, in the melt aluminum shifts the iron precipitation boundary toward drastically lower iron contents at which the iron particles precipitate or form intermetallic particles together with other elements.
Calcium exhibits a pronounced grain refining effect and worsens the castability and corrosion resistance.
Undesirable accompanying elements in magnesium alloys include iron, nickel, cobalt and copper, which cause a considerable increase in the corrosion tendency due to the electropositive nature thereof.
Manganese can be found in all magnesium casting alloys and binds iron in the form of AlMnFe precipitations, whereby the formation of local elements is reduced. On the other hand, manganese is not able to bind all the iron, and therefore a remainder of iron and a remainder of manganese always remain in the melt.

Implant materials comprise polymers, metallic materials, and ceramic materials (as coatings, for example). Biocompatible metals and metal alloys for permanent implants comprise, for example, stainless steels (such as 316L), cobalt-based alloys (such as CoCrMo cast alloys, CoCrMo forge alloys, CoCrWNi forge alloys and CoCrNiMo forge alloys), technical pure titanium and titanium alloys (such as cp titanium, TiAl6V4 or TiAl6Nb7) and gold alloys. In the field of biocorrodible stents, the use of magnesium or technical pure iron as well as biocorrodible base alloys of the elements magnesium, iron, zinc, molybdenum, and tungsten are proposed.

The use of biocorrodible magnesium alloys for temporary implants having filigree structures is made difficult in particular in that the degradation of the implant progresses very quickly in vivo. So as to reduce the corrosion rate, this being the degradation speed, different approaches are being discussed. For one, it is attempted to slow the degradation on the part of the implant material by developing appropriate alloys. In addition, coatings are to bring about a temporary inhibition of the degradation. While the existing approaches are promising, none of them has so far led to a commercially available product. Regardless of the efforts made so far, there is rather a continuing need for solutions that make it possible to at least temporarily reduce the corrosion of magnesium alloys in vivo, while optimizing the mechanical properties thereof at the same time.

In light of this prior art, the objects of the invention are that of providing a biodegradable magnesium alloy, a method for the production thereof and a use for implants, which allow the magnesium matrix of the implant to remain in an electrochemically stable state over the required support period with fine grain and high corrosion resistance without protective layers, and to utilize the formation of intermetallic phases, which electrochemically are more noble than the magnesium matrix, while also improving the mechanical properties, such as increasing the tensile strength and proof stress, as well as reducing the mechanical asymmetry so as to adjust the degradation rate of the implants.

These objects are achieved by a magnesium alloy having the characteristics of claim 1, a method having the characteristics of claim 11, and the use according to the characteristics of claims 21 and 23.

The characteristics listed in the dependent claims allow advantageous refinements of the magnesium alloy according to the invention, of the method for the production thereof according to the invention, and the use according to the invention.

The solution according to the invention is based on the realization that the corrosion resistance and deformability of the magnesium matrix of the implant must be assured over the support period such that the implant is able to absorb multiaxial permanent load without fracture or cracking, and to also utilize the magnesium matrix as a means for the decomposition triggered by the physiological liquids.

This is achieved by the magnesium alloy comprising:
3 to 7% by weight Zn, 0.001 to 0.5% by weight Ca, the remainder being magnesium containing total impurities, which promote electrochemical potential differences and/or the formation of intermetallic phases, in a total amount of no more than 0.0048% by weight, preferably no more than 0.0045% by weight and still more preferably no more than 0.0036% by weight, wherein the total impurity contains:

- individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Cu, Al, Zr and P in an amount of not more than 0.0038% of weight; and
- alloying elements selected from the group of the rare earths having the ordinal numbers 21, 39, 57 to 71 and 89 to 103 in an amount of no more than 0.001% by weight.

The magnesium alloy according to the invention has extraordinarily high corrosion resistance, which is achieved by drastically reducing the content of individual impurities and the combinations thereof in the magnesium matrix, and by also adding precipitation and solid solution hardenable elements, which must be present in completely solid solution. The microstructure that is obtained has no electrochemical potential differences between the individual matrix phases after the forming and heat treatment processes, and therefore these differences cannot expedite the corrosion in physiological media.

The applicant surprisingly found that the alloy matrix, having a content of 3 to 5% by weight Zn and 0.2 to 0.4% by weight Ca, has a more noble electrochemical potential than the intermetallic phase $Ca_2Mg_6Zn_3$, while the MgZn phase, which can be precipitated by heat treatment, is considerably more noble as compared to the alloy matrix, whereby the MgZn phase can be precipitated from the lattice of the alloy matrix by means of targeted heat treatment and can act as cathodes for the alloy matrix. This provides the option of deliberately influencing the degradation rate of the alloy matrix.

Another surprising result is that, despite freedom of Zr, or Zr contents that are considerably lower than those stated in the prior art, a grain refining effect can be achieved which is attributed to the intermetallic phase $Ca_2Mg_6Zn_3$, which blocks the movements of the grain boundaries, limits the grain size during recrystallization and thus prevents undesirable grain growth, while also increasing the proof stress and tensile strength values.

Within the meaning of the aforementioned mechanical properties, a Zr content of <0.0003% by weight, and preferably <0.0001% by weight, is advantageous for the magnesium alloy according to the invention.

The previously known tolerance limits for the individual impurities within the total impuritiy do not take into account that wrought magnesium alloys often times are subjected to a thermomechanical treatment, and more particularly to an extended annealing process, which creates the near-equilibrium structures. The metallic elements bond by way of diffusion and form what are known as intermetallic phases, which have a different electrochemical potential, notably a considerably higher potential, than the magnesium matrix, and therefore these intermetallic phases act as cathodes and can trigger galvanic corrosion processes.

The applicant found that a formation of such intermetallic phases can be reliably prevent when complying with the following tolerance limits of the individual impurities within the total impurity:

Fe, Si, Mn, Co, Ni, Cu each with <0.0005% by weight; Zr, Al each with <0.0003% by weight; and P <0.0002% by weight.

It is noted that in this embodiment the total impurity additionally contains individual impurities selected from the group of rare earths having the ordinal numbers 21, 57 to 71 and 89 to 103 in total <0.001% by weight, preferably no more than 0.0005% by weight and still more preferably no more than 0.0003% by weight..

Preferably the corrosion-staple alloy matrix contains total impurities in a total amount of no more than 0.0036 % by weight, containing individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Al, Zr, and P of in total no more than 0,0026% by weight, wherein the total amount can be achieved when complying with the following tolerance limits of individual impurities in % by weight:
Fe, Si, Mn each with <0.0005; Co, Ni, Cu each with <0.0002; Zr, <0.0003;
and P, Al each with <0.0001.
Additionally the total impurities contain the preferred amount of rare earths having the ordinal numbers 21, 57 to 71 and 89 to 103 in total <0.001.

In particular preferred the corrosion-staple alloy matrix contains total impurities in a total amount of no more than 0.00215 % by weight, containing individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Al, Zr, and P of in total no more than 0,00115% by weight, wherein the total amount can be achieved when complying with the following tolerance limits of individual impurities in % by weight:
Fe, Si, Mn each with <0.0002; Co, Ni, Cu, Zr, P each with <0.0001; and Al <0.00005.
Additionally the total impurities contain the preferred amount of rare earths having the ordinal numbers 21, 57 to 71 and 89 to 103 in total <0.001.

When the individual impurities are combined, the formation of intermetallic phases, which are more noble than the alloy matrix, is suppressed if the sum of individual impurities consisting of Fe, Si, Mn, Co, Ni, Cu and Al is no more than 0.0033% by weight, preferably no more than 0.0022% by weight, still more preferably no more than 0.00095% by weight, the content of Al is no more than 0.0003% by weight, preferably no m ore than 0.0001% by weight, particularly preferably no more than 0.00005% by weight

and the content of Zr is preferably no more than 0.0003% by weight, preferably no more than 0.0001% by weight.

There are different mechanisms of action by which the aforementioned individual impurities impair the corrosion resistance of the material.

If small Fe particles form in the alloy because of a high Fe content, these particles will act as cathodes for a corrosive attack; the same applies to Ni and Cu.

Moreover, especially Fe and Ni with Zr, but also Fe, Ni and Cu with Zr, can precipitate as intermetallic particles in the melt; these will also act as very effective cathodes for corrosion of the matrix.

Intermetallic particles having a very high potential difference as compared to the matrix and a very high formation tendency include the phases of Fe and Si and Fe, Mn and Si, which is why contaminations containing these elements must be minimized.

The content of P should be minimized to the extent possible, because Mg phosphides form even when minute amounts of P are present and dramatically impair the mechanical properties of the structure.

Such low concentrations thus ensure that the magnesium matrix no longer contains any intermetallic phases, which have a more positive electrochemical potential as compared to the matrix.

In the magnesium alloy according to the invention, the sum of the contents of elements of the rare earths and scandium (ordinal numbers 21, 57 to 71 and 89 to 103) is less than 0.001% by weight, preferably less than 0.0005% by weight and still more preferably less than 0.0003.

These additions make it possible to increase the tensile strength of the magnesium matrix and raise the electrochemical potential of the matrix, whereby a corrosion-reducing action, notably with respect to physiological media, develops. The precipitations preferably have a size of no more than 5 μm, and preferably of no more than 1 μm, and are located on the grain boundaries and in the grain interior, whereby the movement of grain boundaries during thermal treatment as well as dislocations during deformation are impaired and the strength of the magnesium alloy is increased.

The magnesium alloy according to the invention achieves a tensile strength of >275 MPa, and preferably >300 MPa, a yield point of >200 MPa, and preferably >225 MPa, and a yield ratio of <0.8, and preferably <075 , wherein the difference between the tensile strength and yield point is >50 MPa, and preferably >100 MPa, and the mechanical asymmetry is <1.25.

These significantly improved mechanical properties of the novel magnesium alloys assure that the implants, for example cardiovascular stents, are able to withstand the multiaxial permanent load in the implanted state over the entire support period, despite onsetting degradation of the magnesium matrix due to corrosion.

So as to minimize the mechanical asymmetry, it is particularly important for the magnesium alloy to have a particularly fine microstructure having a grain size of no more than 5 μm.

The objects of the invention are moreover achieved by a method for producing a magnesium alloy having improved mechanical and electrochemical properties. The method comprises the following steps:

a) generating a high-purity magnesium by way of vacuum distillation;

b) generating a billet of the alloy by synthesis of the magnesium according to step a) with high-purity Zn and Ca in a composition of 3 to 7% by weight Zn, 0.001 to 0.5% by weight Ca, the remainder being magnesium containing total impurities, which promote electrochemical potential differences and/or the formation of intermetallic phases, in a amount of no more than 0.0048 by weight, preferably no more than 0.0045 % by weight and still more preferably no more than 0.0036% by weight, wherein the total impurity contains individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Cu, Al, Zr and P in an amount of not more than 0.0038% of weight; and wherein the alloying elements are selected from the group of the rare earths having the ordinal numbers 21, 39, 57 to 71 and 89 to 103 in a total amount of no more than 0.001% by weight;

c) homogenizing the alloy by annealing at a temperature between 350°C and 450°C with a holding period of 4 to 40 hours;

c) for the addition elements which are also contained in the total impurities:
rare earths in a total amount of no more than 0.001% by weight, preferably no more than 0.0005% by weight.

It is particularly advantageous that the method according to the invention only requires a small number of forming steps. Extrusion, equal channel angular extrusion and/or multiple forging can thus preferably be employed, which assure that a substantially homogeneous fine grain of <15 µm is achieved.
Because of the heat treatment, MgZn precipitations having a grain size of 1 nm to 50 nm in a fine-grained structure having a grain size of preferably <7.5 µm dispersely distributed at the grain boundaries and in the interior of the grains, whereby the tensile strength of the alloy reaches values which at >275 MPa, and preferably >300 MPa, are considerably higher than the prior art.

A third concept of the invention relates to the use of the magnesium alloy produced according to the invention, which has the aforedescribed advantageous composition and structure, in medical technology, notably for the production of implants, for example endovascular implants such as stents, for fastening and temporarily fixing tissue implants and tissue transplantations, orthopedic and dental implants, and neuroimplants.

All implants in the sense of this patent application are in the Cardiovascular field, osteosynthesis field or other areas.

Cardiovascular field in the sense of this application means
- the field of diagnostic, prevention and treatment of all diseases of the cardiovascular system, i.e. heart and blood vessel system,
- by mean of active and non-active implants used to support vessels, and vein systems
- including coronary, cerebral and peripheral vascular implants like stents, valves, closure devices, occluders, clips, coils, staples, implantable regional drug delivery devices,
- implantable electrostimulators (like pacemakers and defibrillators), implantable monitoring devices, implantable electrodes,

# MAGNESIUM ALLOY, METHOD FOR THE PRODUCTION THEREOF AND USE THEREOF

This patent application relates to a magnesium alloy and to a method for the production thereof and to the use thereof.

It is known that the properties of magnesium alloys are decisively defined by the type and quantity of the alloying elements and impurities as well as the production conditions. The effects of the alloying elements and impurities on the properties of the magnesium alloys have been long known to a person skilled in the art and illustrate the complex nature of determining the properties of binary or ternary magnesium alloys for the use thereof as implant materials.

The alloying element used most frequently for magnesium is aluminum, resulting in increased tensile strength due to solid solution and precipitation hardening and fine grain formation, but also in microporosity. Moreover, in the melt aluminum shifts the iron precipitation boundary toward drastically lower iron contents at which the iron particles precipitate or form intermetallic particles together with other elements.

Calcium exhibits a pronounced grain refining effect and worsens the castability and corrosion resistance.

Undesirable accompanying elements in magnesium alloys include iron, nickel, cobalt and copper, which cause a considerable increase in the corrosion tendency due to the electropositive nature thereof.

Manganese can be found in all magnesium casting alloys and binds iron in the form of AlMnFe precipitations, whereby the formation of local elements is reduced. On the other hand, manganese is not able to bind all the iron, and therefore a remainder of iron and a remainder of manganese always remain in the melt.

Implant materials comprise polymers, metallic materials, and ceramic materials (as coatings, for example). Biocompatible metals and metal alloys for permanent implants comprise, for example, stainless steels (such as 316L), cobalt-based alloys (such as CoCrMo cast alloys, CoCrMo forge alloys, CoCrWNi forge alloys and CoCrNiMo forge alloys), technical pure titanium and titanium alloys (such as cp titanium, TiAl6V4 or TiAl6Nb7) and gold alloys. In the field of biocorrodible stents, the use of magnesium or technical pure iron as well as biocorrodible base alloys of the elements magnesium, iron, zinc, molybdenum, and tungsten are proposed.

The use of biocorrodible magnesium alloys for temporary implants having filigree structures is made difficult in particular in that the degradation of the implant progresses very quickly in vivo. So as to reduce the corrosion rate, this being the degradation speed, different approaches are being discussed. For one, it is attempted to slow the degradation on the part of the implant material by developing appropriate alloys. In addition, coatings are to bring about a temporary inhibition of the degradation. While the existing approaches are promising, none of them has so far led to a commercially available product. Regardless of the efforts made so far, there is rather a continuing need for solutions that make it possible to at least temporarily reduce the corrosion of magnesium alloys in vivo, while optimizing the mechanical properties thereof at the same time.

In light of this prior art, the techniques disclosed herein may allow for provision of a biodegradable magnesium alloy, a method for the production thereof and a use for implants, which may allow the magnesium matrix of the implant to remain in an electrochemically stable state over the required support period with fine grain and high corrosion resistance without protective layers, and to utilize the formation of intermetallic phases, which electrochemically are more noble than the magnesium matrix, while also improving the mechanical properties, such as increasing the tensile strength and proof stress, as well as reducing the mechanical asymmetry so as to adjust the degradation rate of the implants.

These may be achieved by a magnesium alloy, a method, and the use according to the independent claims.

The characteristics listed in the dependent claims allow advantageous refinements of the magnesium alloy, method or use according to the independent claims.

The solution may allow for the corrosion resistance and deformability of the magnesium matrix of the implant to be assured over the support period such that the implant is able to absorb multiaxial permanent load without fracture or cracking, and to also utilize the magnesium matrix as a means for the decomposition triggered by the physiological liquids.

This is achieved by the magnesium alloy comprising:
3 to 7% by weight Zn, 0.001 to 0.5% by weight Ca, the remainder being magnesium containing total impurities, which promote electrochemical potential differences and/or the formation of intermetallic phases, in a total amount of no more than 0.0048% by weight, preferably no more than 0.0045% by weight and still more preferably no more than 0.0036% by weight, wherein the total impurity contains:

- individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Cu, Al, Zr and P in an amount of not more than 0.0038% of weight; and
- alloying elements selected from the group of the rare earths having the ordinal numbers 21, 39, 57 to 71 and 89 to 103 in an amount of no more than 0.001% by weight.

The magnesium alloy as disclosed herein may have extraordinarily high corrosion resistance, which may be achieved by drastically reducing the content of individual impurities and the combinations thereof in the magnesium matrix, and by also adding precipitation and solid solution hardenable elements, which may be present in completely solid solution. The microstructure that is obtained may have no electrochemical potential differences between the individual matrix phases after the forming and heat treatment processes, and therefore these differences cannot expedite the corrosion in physiological media.

The applicant surprisingly found that the alloy matrix, having a content of 3 to 5% by weight Zn and 0.2 to 0.4% by weight Ca, has a more noble electrochemical potential than the intermetallic phase $Ca_2Mg_6Zn_3$, while the MgZn phase, which can be precipitated by heat treatment, is considerably more noble as compared to the alloy matrix, whereby the MgZn phase can be precipitated from the lattice of the alloy matrix by means of targeted heat treatment and can act as cathodes for the alloy matrix. This provides the option of deliberately influencing the degradation rate of the alloy matrix.

Another surprising result is that, despite freedom of Zr, or Zr contents that are considerably lower than those stated in the prior art, a grain refining effect can be achieved which is attributed to the intermetallic phase $Ca_2Mg_6Zn_3$, which blocks the movements of the grain boundaries, limits the grain size during recrystallization and thus prevents undesirable grain growth, while also increasing the proof stress and tensile strength values.

Within the meaning of the aforementioned mechanical properties, a Zr content of <0.0003% by weight, and preferably <0.0001% by weight, is advantageous for the magnesium alloy disclosed herein.

The previously known tolerance limits for the individual impurities within the total impurity do not take into account that wrought magnesium alloys often times are subjected to a thermomechanical treatment, and more particularly to an extended annealing process, which creates the near-equilibrium structures. The metallic elements bond by way of diffusion and form what are known as intermetallic phases, which have a different electrochemical potential, notably a considerably higher potential, than the magnesium matrix, and therefore these intermetallic phases act as cathodes and can trigger galvanic corrosion processes.

The applicant found that a formation of such intermetallic phases can be reliably prevented when complying with the following tolerance limits of the individual impurities within the total impurity:

Fe, Si, Mn, Co, Ni, Cu each with <0.0005% by weight; Zr, Al each with <0.0003% by weight; and P <0.0002% by weight.

It is noted that in this embodiment the total impurity additionally may contain individual impurities selected from the group of rare earths having the ordinal numbers 21, 57 to 71 and 89 to 103 in total <0.001% by weight, preferably no more than 0.0005% by weight and still more preferably no more than 0.0003% by weight..

Preferably the corrosion-staple alloy matrix contains total impurities in a total amount of no more than 0.0036 % by weight, containing individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Al, Zr, and P of in total no more than 0,0026% by weight, wherein the total amount can be achieved when complying with the following tolerance limits of individual impurities in % by weight:

Fe, Si, Mn each with <0.0005; Co, Ni, Cu each with <0.0002; Zr, <0.0003; and P, Al each with <0.0001.

Additionally the total impurities may contain the preferred amount of rare earths having the ordinal numbers 21, 57 to 71 and 89 to 103 in total <0.001.

In particular the preferred corrosion-staple alloy matrix may contain total impurities in a total amount of no more than 0.00215 % by weight, containing individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Al, Zr, and P of in total no more than 0,00115% by weight, wherein the total amount can be achieved when complying with the following tolerance limits of individual impurities in % by weight:

Fe, Si, Mn each with <0.0002; Co, Ni, Cu, Zr, P each with <0.0001; and Al <0.00005.

Additionally the total impurities may contain the preferred amount of rare earths having the ordinal numbers 21, 57 to 71 and 89 to 103 in total <0.001.

When the individual impurities are combined, the formation of intermetallic phases, which are more noble than the alloy matrix, may be suppressed if the sum of individual impurities consisting of Fe, Si, Mn, Co, Ni, Cu and Al is no more than 0.0033% by weight, preferably no more than 0.0022% by weight, still more preferably no more than 0.00095% by weight, the content of Al is no more than 0.0003% by weight, preferably no m ore than 0.0001% by weight, particularly preferably no more than 0.00005% by weight

and the content of Zr is preferably no more than 0.0003% by weight, preferably no more than 0.0001% by weight.

There are different mechanisms of action by which the aforementioned individual impurities impair the corrosion resistance of the material.

If small Fe particles form in the alloy because of a high Fe content, these particles will act as cathodes for a corrosive attack; the same applies to Ni and Cu.

Moreover, especially Fe and Ni with Zr, but also Fe, Ni and Cu with Zr, can precipitate as intermetallic particles in the melt; these will also act as very effective cathodes for corrosion of the matrix.

Intermetallic particles having a very high potential difference as compared to the matrix and a very high formation tendency may include the phases of Fe and Si and Fe, Mn and Si, which is why contaminations containing these elements must be minimized.

The content of P should be minimized to the extent possible, because Mg phosphides form even when minute amounts of P are present and dramatically impair the mechanical properties of the structure.

Such low concentrations thus ensure that the magnesium matrix no longer contains any intermetallic phases, which have a more positive electrochemical potential as compared to the matrix.

In the magnesium alloy disclosed herein, the sum of the contents of elements of the rare earths and scandium (ordinal numbers 21, 57 to 71 and 89 to 103) may be less than 0.001% by weight, preferably less than 0.0005% by weight and still more preferably less than 0.0003.

These additions make it possible to increase the tensile strength of the magnesium matrix and raise the electrochemical potential of the matrix, whereby a corrosion-reducing action, notably with respect to physiological media, may develop. The precipitations preferably have a size of no more than 5 µm, and preferably of no more than 1 µm, and are located on the grain boundaries and in the grain interior, whereby the movement of grain boundaries during thermal treatment as well as dislocations during deformation may be impaired and the strength of the magnesium alloy may be increased.

The magnesium alloy disclosed herein may achieve a tensile strength of >275 MPa, and preferably >300 MPa, a yield point of >200 MPa, and preferably >225 MPa, and a yield ratio of <0.8, and preferably <075 , wherein the difference between the tensile strength and yield point may be >50 MPa, and preferably >100 MPa, and the mechanical asymmetry may be <1.25.

These significantly improved mechanical properties of the magnesium alloys may allow the implants, for example cardiovascular stents, to be able to withstand the multiaxial permanent load in the implanted state over the entire support period, despite onsetting degradation of the magnesium matrix due to corrosion.

So as to minimize the mechanical asymmetry, it is particularly important for the magnesium alloy to have a particularly fine microstructure having a grain size of no more than 5 µm.

In another exemplary technique, there is provided a method for producing a magnesium alloy having improved mechanical and electrochemical properties. The method comprises the following steps:

a) generating a high-purity magnesium by way of vacuum distillation;

b) generating a billet of the alloy by synthesis of the magnesium according to step a) with high-purity Zn and Ca in a composition of 3 to 7% by weight Zn, 0.001 to 0.5% by weight Ca, the remainder being magnesium containing total impurities, which promote electrochemical potential differences and/or the formation of intermetallic phases, in a amount of no more than 0.0048 by weight, preferably no more than 0.0045 % by weight and still more preferably no more than 0.0036% by weight, wherein the total impurity contains individual impurities selected from the group of Fe, Si, Mn, Co, Ni, Cu, Al, Zr and P in an amount of not more than 0.0038% of weight; and wherein the alloying elements are selected from the group of the rare earths having the ordinal numbers 21, 39, 57 to 71 and 89 to 103 in a total amount of no more than 0.001% by weight;

c) homogenizing the alloy by annealing at a temperature between 350ºC and 450ºC with a holding period of 4 to 40 hours;

c) for the addition elements which are also contained in the total impurities:
rare earths in a total amount of no more than 0.001% by weight, preferably no more than 0.0005% by weight.

It is particularly advantageous that the method disclosed herein may only require a small number of forming steps. Extrusion, equal channel angular extrusion and/or multiple forging can thus preferably be employed, which assure that a substantially homogeneous fine grain of <15 µm is achieved.
Because of the heat treatment, MgZn precipitations having a grain size of 1 nm to 50 nm in a fine-grained structure having a grain size of preferably <7.5 µm dispersely distributed at the grain boundaries and in the interior of the grains, whereby the tensile strength of the alloy reaches values which at >275 MPa, and preferably >300 MPa, may be considerably higher than the prior art.

In another exemplary technique, there is provided a use of the magnesium alloy produced according to the method disclosed herein, which may have the aforedescribed advantageous composition and structure, in medical technology, notably for the production of implants, for example endovascular implants such as stents, for fastening and temporarily fixing tissue implants and tissue transplantations, orthopedic and dental implants, and neuroimplants.

All implants in the sense of this patent application are in the Cardiovascular field, osteosynthesis field or other areas.

Cardiovascular field in the sense of this application means

- the field of diagnostic, prevention and treatment of all diseases of the cardiovascular system, i.e. heart and blood vessel system,
- by mean of active and non-active implants used to support vessels, and vein systems
- including coronary, cerebral and peripheral vascular implants like stents, valves, closure devices, occluders, clips, coils, staples, implantable regional drug delivery devices,
- implantable electrostimulators (like pacemakers and defibrillators), implantable monitoring devices, implantable electrodes,