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Research Progress on Biodegradable Zn-Based Alloy Materials

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Abstract: As biodegradable materials for biomedical purposes, people have done a lot of research on Mg alloy and Fe alloy. However, both types of materials have obvious shortcomings. Mg alloy degrades too rapid and the inhomogeneity degradation rate in the human environment, resulting in its mechanical properties rapidly declining and it cannot provide adequate support or fixing capacity. Fe alloy has a very slow degradation rate due to the good protective effect of its degradation products, resulting in similar problems to non-degradable material. In this situation, Zn alloys are often mentioned in recent years, because Zn is an essential trace element for the human body, and the standard potential of Zn is between Mg and Fe, so its degradation rate is excellent. At the same time, Zn-based alloy has become a new biodegradable biomedical material after Mg alloy and Fe alloy, and has been widely used in cardiovascular stents, bone implants and internal fixation devices, and gastrointestinal staplers. At present, there is no systematic research result on biodegradable biomedical Zn-based Alloy Materials, the research interests include composition design, processing and preparation, degradation principle, biocompatibility, mechanical properties in all aspects. This article reviewed the properties of Zn-based Alloy Materials compared with other typical alloys and pointed out the future development direction.

Keywords: Zn-Based Alloy, Trace Elements, Biocompatibility, Degradation Rate, Mechanical Property

1. Introduction

In disease treatment area, biomedical material as a kind of functional material is usually used to repair human organs or tissues. During the repairing process, there are no adverse reactions to human organs or tissues, that is, no side effects [1]. With the development of biomedical materials, most tissues and organs of the human body can be replaced with biomedical materials except brain. Because of the direct use in the human body, the demand for biomedical material is higher and higher. One kind of the materials is non-biodegradable material. Once it is implanted in the human body, it will produce a series of physical reactions which need the transplant recipients to take medication against immunity resistance, sometimes needs to have surgery to remove it. Obviously, this will increase the patients' pain, therefore, non-degradable biomedical materials are gradually abandoned [2]. Because of this, biodegradable biomedical materials have been developed as new materials in the field of disease treatment [3].

Biodegradable biomedical materials can be traced back to 1901. At that time, in order to protect blood vessels from blood clots, Swiss doctor Erwin Payr first used artificial magnesium alloy blood vessels to implant into the patients. It was also used for keeping the joint stable. Both tests were successful [4]. In 1907, Belgian doctor A. Lambotte first used pure magnesium plates and gold-plated steel nails to repair patients with leg fractures. During the repair process, he found that magnesium is degradable [5]. As early as 1949, the United States did research on medical polymer materials and published high-level medical papers on it. At that time, two parts of research work were done: one was to replace human joints, femurs and even skulls with plexiglass, and the other was to replace surgical sutures with polyamide fibers, both of which have achieved good results. These should be regarded as the beginning of biomedical polymer materials, and subsequent work is gradually carried out [6]. Recently, biodegradable biomedical materials are mainly used in heart stents. For example, in 2001, M. Peuster et al. from Hannover University of Veterinary Medicine in Germany conducted a study on pure iron stents. They used New Zealand white rabbits as test specimens, implanted 16 pure iron stents in their aorta, and removed the pure iron stents at different intervals of 6 months, 12 months and 18 months. Finally, angiographic tests were conducted on the aorta of New Zealand white rabbits, and the test results showed that after implantation of pure iron stent, no occlusion or thrombosis occurred in the aorta, and the aortic vascular unblocked rate was 100% [7].

At present, biodegradable biomedical materials are mainly used in cardiovascular stents, bone implants and internal fixation devices, and gastrointestinal anastomoses. This makes it necessary to meet three requirements at the same time: 1) suitable degradation rate; (2) excellent biocompatibility; (3) excellent mechanical properties. These three requirements are interdependent, so the design and development of biodegradable biomedical materials should not only pay attention to the structure of the material, but also the functionality of the material [8]. As metal base materials Mg, Fe and its alloys are the most representative biodegradable biomedical materials. Through the research by many scholars, it was found that Mg and its alloys would appear bubbles shortly after implantation in the human body, and a large number of gases were determined to be alkaline, resulting in an increase in local PH value after implantation. After that, the degradation rate of Mg and its alloys will be uneven in the process of degradation, and the degradation rate in some places will be very fast, while the degradation rate in some places will be very slow. The mechanical properties of materials in places with fast rates cannot be guaranteed, and they cannot provide sufficient supporting force and fixing ability [9]. On the contrary, the degradation rate of Fe and its alloys is slow after implantation into the human body, resulting in the same problem as previously mentioned [10].

Zn is one of the essential trace elements in the human body. It is involved in almost all physiological and metabolic processes in the body, and is also a component element of more than 200 enzymes in the human body. Zn plays an important role in the growth and development of the human body as well as the immune system, nervous system and metabolic system. Zn has an impact on the regulation of gene expression because it is an essential component of DNA polymerase, which regulates DNA replication, translation, and transcription. Zn plays an important role in the synthesis of growth hormone and the maintenance of hippocampus function, and also participates in the metabolism of nucleic acid protein, which can promote the normal development of skin, bone and sexual organs, and plays an important role in human growth and development. The standard electrode potential of Zn (-0.763V) is between Mg (-2.372V) and Fe (-0.447V) [11], and the degradation rate of biomedical materials mainly depends on the standard electrode potential. Therefore, Zn as the main element of degradable biomedical materials has been paid more and more attention. At the same time, It has been proven in medicine for a long time that Zn is almost entirely involved in the physiological reaction of the human body, such as human nervous system control, immune system coordination, gene growth, cell development and so on. According to incomplete statistics, the total amount of Zn element in an adult body is about 2 g. The daily intake of Zn should be between 5 mg and 20 mg [12]. Due to the poor mechanical properties of pure Zn, scholars have added Mg, Ca, Ag and Sr as alloy-elements into the alloy to become a new biodegradable biomedical ZN-based alloy [13], and studied them separately. Based on the above research results, the biological compatibility, degradation rate and mechanical properties of biodegradable biomedical materials are comprehensively reviewed in this paper, and their future development direction is also discussed.

2. Component Element Analysis

2.1. Element Zn

Zn is the main element in degraded biomedical Zn-based alloy. From a biological standpoint, Zn is involved in the entire cellular metabolic process, including enzyme metabolism, normal operation of immune system, DNA and RNA, as well as the growth of body, taste and smell [14]. In 2013, P. K. Bowen and other scholars from Michigan Technological University in the United States found that the metal wire made of pure zinc was implanted into the rat living arterial blood tube to test the degradation rate, and the data obtained were sorted after the experiment. The conclusion is that in the first three months, the degradation rate of the wire made of pure zinc in the rat arterial blood tube is 0.2mm per year, the first three months is the time turning point, and then the degradation rate of the wire made of pure zinc gradually increases. According to the final degradation rate, the existence time of the wire made of pure zinc would not be too long. When the wire made of pure zinc was taken out at the end of the experiment, it was found through medical observation that there was no abnormality in the arterial tissue of the rats, and the tissue was completely covered by the wire made of pure zinc after it was taken out, and no adverse reactions occurred in the rats. In order to prove the accuracy of this test, P. K. Bowen et al. then conducted a comparative test, implanted Zn alloy, Mg alloy and Fe alloy respectively in the abdominal aorta of adult female rats, calculated the degradation rate of different alloys by sorting out the data, and concluded that the degradation rate of Zn alloy was moderate. Far superior to the other two alloys [15]. In the field of orthopedics, it has been found that Zn also plays a role in promoting mineral deposition and accelerating bone growth in terms of bone mass preservation [16]. On the other hand, there is another kind of osteoclasts, which inhibit bone resorption, and Zn element will also play an inhibitory role, inhibiting the absorption of osteoclasts [17]. If a decrease in Zn content in bone matrix is detected during physical examination of normal people, a comprehensive examination of the orthopedic department is needed to make a judgment on bone aging and bone diseases [18]. At present, Zn element has been widely used in the field of biology, and the biological field regards Zn element as "the calcium element of the 21st century" [19].

2.2. Element Mg

Among all biodegradable biomedical metal materials, Mg element is the one of that gets the most attention. Since the early 20th century, there has been research on the application of Mg as a biodegradable biomedical material. However, from the perspective of clinical use, only WE43, an alloy composed of Mg elements, has been put into use, and it is only used for cardiovascular stents [20]. As a biodegradable biomedical material, the most important evaluation index is the degradation rate, and the fast degradation rate of Mg element and its alloy makes it difficult to industrialization. On the one hand, the Mg element and its alloy will appear bubbles shortly after implantation into the human body, which is clinically manifested as emphysema, and the emphysema aggregation occupies the tissue repair site and inhibits the repair process. On the other hand, Mg will also produce alkaline ions during degradation, and the internal environment of tissues will also change over a long period of time. Once the internal alkaline environment of tissues appears, the tissue repair process will be slowed down [21]. In view of the drawbacks of the above Mg element and its alloy as a degradable biomedical metal material, many scholars at home and abroad have spent 20 years to do a lot of research, and the main conclusions are as follows [22]:

2.2.1. Improve the Purity of Mg

Pure Mg is theoretically free of impurities, so it does not release other elements after implantation in the body. However, pure Mg does contain some impurities, such as Fe, Ni, Cu, etc. Once these impurities exist, electrochemical reactions will occur, and the corrosion rate of Mg will be greatly increased [23]. And the research has shown that the main difference between High purity Mg (where ω (Fe) is about 0.0045%, ω (Cu) < 0.002%, ω (Ni) < 0.002%) and commercial pure magnesium (where ω (Fe) is 0.02%, ω (Cu) < 0.002% ω (Cu), ω (Ni) < 0.002%) is in Fe content. But the degradation rate in Hank's solution is very different, the degradation rate of high-purity Mg is thousands of times slower than that of commercial pure Mg [24].

2.2.2. Change the Alloy Composition

Mg is the main element of the alloy, to a certain extent, its composition determines the biocompatibility, degradation rate and mechanical properties. In 2005, M. Peuster and other scholars from the University of Veterinary Medicine in Hannover, Germany, studied the implantation behavior of as-cast AZ31, AZ91, LAE442 and WE43 magnesium alloys in the femur of guinea pigs. The results of the study showed that H_2 air sacs were found under the skin of guinea pigs in all experimental groups 1 week after implantation, but these air sacs disappeared on their own after 2 to 3 weeks without adverse effects. At the same time, during the degradation process, a Ca-containing and P-containing mineral layer is formed on the surface of the alloy composed of these four Mg elements and the layer is in direct contact with the surrounding bone tissue. Compared with PLA control group, after 6 and 18 weeks of implantation, the implantation of the alloy of Mg elements increased new bone growth in the periosteum and internal periosteum [25].

2.2.3. Surface Modification

The degradation rate of Mg alloy can be controlled to a certain extent by surface modification, and its surface biocompatibility and mechanical properties can be improved. In general, the common surface modification methods of alloys composed of Mg elements can include: mechanical methods, chemical methods and physical methods. Mechanical methods include organic processing, grinding, milling, polishing and laser shot peening. Chemical methods usually include chemical cap, electrochemical treatment, biomimetic precipitation, sol-gel treatment, organic and polymer coating, etc. Physical methods usually include ion implantation, plasma immersion, ion implantation and deposition, ion beam assisted deposition, physical vapor deposition, plasma enhanced chemical vapor deposition and ion plating, etc. [26].

2.3. Element Ca

In the field of physiology and medicine, the Ca element, as the main component of human bone tissue, directly participates in the expression of chemical signals among cells. At the same time, studies have shown that the absorption of Mg element by Ca element in human bone tissue plays a positive role. When human bone tissue is damaged, Mg ion and Ca ion can also promote healing and growth [27]. In the field of metal materials, the Ca element can play a role in refining grains. According to the phase diagram, the maximum solubility of Ca in Mg is 1.34%. For this reason, Mg is the main element in the alloy composed of Ca elements, and with the increase of Ca content, the second phase Mg_2Ca can be precipitated. This intermetallic compound plays a role in refining the grain and improving the strength of the material. In 2010, A. Drynda et al., University of Rostock, Germany, found that in alloys composed of Ca content, the plasticity of the alloys decreased with the increase of Ca element [28]. In the same year, A. Krause et al. from the University of Veterinary Medicine in Hannover, Germany, found that in the live experiment of rabbit tibia, the degradation rate of the alloy composed of Ca elements exceeded 50% within 6 months after implantation [29].

2.4. Element Ag

In the history of medical application, the Ag element has a wide range of uses, such as acupuncture needles commonly used in traditional Chinese medicine, dental abutment materials used in stomatology department, medical film, surgical AIDS and medical devices. The main reason why Ag element is widely used is that after Ag element enters the human body, polymer proteins in the body directly or indirectly combine with Ag element, and then are absorbed, transported, stored and metabolized, and finally exhibit biological activity in the form of protein binding [30]. At the same time, many medical tests have proved that the use of Ag element as an antibacterial material can also achieve excellent bactericidal effect, and the bactericidal range is wide [31]. As a biomedical material, Ag and its alloys can also enter the human body. Tests have proved that Ag element will not cause lesions even if it stays in the body for a long time, and Ag element itself has good biocompatibility, and this technology has been applied very early in surgical operations [32]. Ag element and its alloy material are often used as fixation materials in surgical operations. For example, Ag plate is used to make bone fixation materials and replacement materials after skull surgery, especially Ag element can be used as replacement materials for skull [33].

2.5. Element Sr

Sr, Mg and Ca belong to the IIA group, and according to the corresponding rules of the periodic table, their chemical, biological and metallurgical properties are basically the same. According to incomplete statistics, a normal adult body contains 320 mg of Sr, 90% of which is located in human bone tissue [34]. In the clinical treatment of osteoporosis, it has been proved that Sr element can stimulate the formation of bone tissue, so many osteoporosis patients take drugs containing Sr salt to improve bone content and reduce the probability of fracture [35]. In the field of electrochemical corrosion, experiments have proved that an appropriate amount of Sr element can appropriately reduce the corrosion rate after implantation in the human body. In 2012, H. S. Brar et al., Department of Materials Science and Engineering, University of Florida, United States, proposed through research that the alloy composed of Sr element can promote bone mineralization after implantation in the human body, and at the same time cause no harmful reaction to the formation of new bone [36].

3. Research on Zn-Based Alloys

3.1. Zn-Mg Base Binary Alloy and Mechanical Properties at Room Temperature

In 2014, Zhou Gongyao and others of Xi 'an Edvansi Medical Technology Co., Ltd. developed a Zn-MG-based binary alloy implant material that can be fully absorbed by the human body for vascular stents, bone nails, etc. The mass fraction of Zn in such alloy materials is 96% ~ 99.998%, and the mass fraction of Mg is 0.002% ~ 4%. The mechanical tests show that the tensile strength of the Zn-Mg base binary alloy is 220 MPa ~340 MPa, the elongation is 11% ~ 29%, and the elastic modulus is 80 GPa. Biological data show that the degradation rate of Zn-Mg based binary alloy is 0.14 mm/year ~3.89 mm/year. In the human environment, the Zn-MG-based binary alloy material can be completely absorbed, which avoids the pain caused by the surgery for the patient. The biological comparison test proves that the degradation rate is better than that of pure Mg and WE43 alloy materials, which avoids the impact of the degradation rate of pure Mg and WE43 alloy materials on the destruction of mechanical support [37]. In 2019, Cui Zeqin et al from Taiyuan University of Technology studied a Zn-Mg based binary alloy material with core-shell structure. The preparation process is to mix 85vol % Zn powder and 15vol % Mg powder with a ball mill, and then obtain the Zn-Mg alloy block material with core-shell structure by SPS sintering. The material was soaked in SBF simulated body fluid, and finally dried to obtain Zn-Mg alloy material with open surface core-shell structure. The mechanical test data show that the density of the Zn-Mg base binary alloy prepared by powder metallurgy can reach 98.5%, the compressive strength is about 215 MPa, the bending strength is 85 MPa, and the bending modulus is 6.0 GPa. At the same time, Cui Zeqin et al. pointed out that the biodegradable biomaterials currently used in clinics mainly include polymer materials and ceramic active materials, but both of them have defects. The mechanical properties of biopolymer materials are low, the degradation of acidic environment will cause local inflammation in patients, and the bioceramic active materials have poor plasticity and lower strength than human bone tissue. Biodegradable biomedical metal materials can not only degrade in the human environment, but also maintain adequate mechanical properties. Zn and Mg elements are the most widely used biodegradable biomedical elements at present, but they also have some shortcomings. When elemental Mg is used as bone implant material, the degradation rate is too fast to match the growth rate of bone tissue. When elemental Zn is used as bone implant material, the mechanical properties are seriously insufficient. It is necessary to prepare Zn-Mg based binary alloy material by adding Mg element to Zn matrix to improve the mechanical properties and meet the conditions for internal service. In addition, it has been proved by studies that the bulk material is not firmly combined with bone tissue as an implant and is easy to loosen. Porous materials are prepared by the powder metallurgy method. Porous materials provide excellent attachment conditions for cells, enable rapid growth of bone cells and bone tissue, and accelerate post-operative recovery of patients [38].

3.2. Zn-Mg-Ag Base Ternary Alloy and Material Ratio

In 2018, Gu Chenxi and others from the First Affiliated Hospital of Zhengzhou University studied a bimetallic material for medical implantation. The inner core of the material is Ti alloy and the outer layer is Zn alloy. The two are connected in the form of dovetail groove, and the two are combined in metallurgy by pouring liquid zinc alloy around titanium alloy at high temperature. The chemical composition of Zn alloy is calculated by mass percentage: Mg is 0.05%~0.8%, Ag is 0.05%~0.5%, the remaining added elements La is 0.1%~0.5%, Se is 0.1%~0.5%, Sr is 0.1%~0.5%, Sn is 0.1%~0.5%, and the residual Zn. It has been proved by biology that these elements are essential and absorbable elements for the human body. After repeated tests, all elements of the Zn-Mg-Ag-based ternary alloy are uniformly released during the degradation process, and the degradation rate is appropriate. After the complete degradation of the Zn-Mg-Ag-based ternary alloy material, the biomedical observation shows that the Zn-Mg-Ag-based ternary alloy material perfectly combines with human tissues without any abnormality [39]. In 2020, Gu Xuenan et al. from Beijing University of Aeronautics and Astronautics studied a microalloyed medical antibacterial Zn- (0.01 wt.%~1 wt.%) Mg- (0.01 wt.%~1 wt.%) Ag alloy. Gu Xuannan et al. obtained through repeated experiments that intermetallic compounds Mg_2Zn_{11} and $AgZn_3$ phases could be formed when Mg and Ag elements were added to Zn, and the grains of Zn matrix were also refined. The results of mechanical properties test show that the yield strength of Zn-Mg-Ag-based alloy materials is 130 MPa ~250 MPa, tensile strength is 150 MPa ~285 MPa, and elongation is 2% ~ 37%. Biomedical test data show that Zn-Mg-Ag-based alloy materials have a good antibacterial effect on Staphylococcus aureus. The antibacterial rate can reach 42% ~ 80%. Zn-mg-ag-based alloy materials have suitable degradation rate and good biocompatibility, and can be widely used in vascular stents, orthopedic implants, surgical suture and other departments [40].

3.3. Zn-Mg-Ca Base Ternary Alloy and Its Medical Properties

In 2017, Shen Chao from the Fourth Military Medical University used a well-type resistance furnace to melt and prepare Zn-1.2Mg-0.1Ca alloy under the protection of CO_2 atmosphere. The specific process was to hold the alloy at 460°C for 20 min, superheat and stir for 5min at 480°C, and then refining, slagging and standing treatment. The ingot of Zn-1.2Mg-0.1Ca alloy was obtained by pouring at 420°C into a steel mold that was fully preheated at 200°C, then standing for 30min and demoulding The research shows that Zn-Mg-Ca alloy materials can withstand two types of corrosion, and the corrosion rate is low, the first corrosion by immersion, its corrosion rate is 0.103 mm/year, the second corrosion by electrochemical way, its corrosion rate is 0.250 mm/year. Secondly, the hydrophilic test data of the Zn-Mg-Ag-based alloy material is good, and the hemolysis rate of the main test index is much lower than 5%, which means that the Zn-Mg-Ag-based alloy material has good blood compatibility and will not cause blood coagulation. Third, Zn-Mg-Ag-based alloy materials can withstand two kinds of cytotoxicity, the first is that MG63 cells showed a good tolerance to Zn-Mg-Ag-based alloy materials, the second is that 3T3 cells showed a good tolerance to its diluted extract, and there was no obvious cytotoxicity in both types of tests. Finally, a comparative test was conducted between Zn-Mg-Ag-based alloy material and WE43 magnesium alloy in the bone marrow cavity of New Zealand rabbits. Due to the low corrosion rate of Zn-Mg-Ag-based alloy material, it continued to provide sufficient mechanical support within 32 weeks after surgery, while WE43 magnesium alloy had degraded 3/4 at 32 weeks after surgery. Shen Chao believed that during the degradation of Zn-Mg-Ag-based alloy material, there was no inflammatory cell infiltration at the interface of bone tissue and no boundary membrane-like material was formed, which could have a good binding force with bone tissue and promote the formation of new bone. The alloy implanted in animal bone has no effect on peripheral heart, liver and kidney function [41]. In 2019, Bai Jing et al from Southeast University studied a biomedical ordered porous Zn-Mg-Ag-based alloy material, which is a porous Ti preform prepared by selective laser melting method to further quantitatively control the microstructure of porous as-cast Zn-Mg-Ca materials, including important parameters such as porosity, pore size and pore distribution. This can meet the diversified requirements of physical structure of porous materials in practical applications. At the same time, this alloy material uses NaF as the raw material, and the anion will not cause corrosion of the Zn-Mg-Ca material during the removal process, thus ensuring that the final prepared porous material has good structural integrity. Finally, the porous material prepared by direct casting molding has fewer internal defects, strong bonding force between grains, and better mechanical properties and service reliability [42].

3.4. Zn-Mg-Sr Ternary Alloy and Biodegradation

In 2015, Cao Yating et al of Shanghai Microinvasive Medical Device (Group) Co., Ltd. developed a Zn-MG-SR-based ternary alloy, in which the main element ω (Mg) <3%, ω (Sr) is 0.001% ~0.5%, and the remaining added element ω (Se) is 0.001% ~0.5%. After testing, the yield strength of this alloy is 200 MPa~ 210 MPa, the tensile strength is 270 MPa~350 MPa, and the elongation is 4% ~12%. In addition, studies have proved that Sr degradation products can play a role in regulating various functions of the human body, and can be completely metabolized and degraded by the human body. At the same time, the implantable medical device made of this alloy material has been tested to have a degradation time of more than 6 months, which can provide mechanical support for a long enough time, and the lumen stent can avoid secondary stenosis [43].

3.5. Zn-Sr Base Binary Alloys and High Temperature Properties

In 2018, Liu Fang from Wuhan University of Science and Technology prepared biodegradable zinc alloys Zn-1Sr and Zn-2Sr by casting and extrusion respectively, and then conducted microhardness tests on different states of alloy materials. The results show that the microhardness of extruded Zn-1Sr and Zn-2Sr alloy is the highest, which is 67 and 96, respectively, while the microhardness of cast Zn-1Sr and Zn-2Sr alloy is the lowest, which is 60 and 89, respectively, indicating that the extrusion process can improve the hardness of Zn-Sr base binary alloy. After that, Liu Fang rolled the extruded Zn-1Sr and Zn-2Sr at 250°C and 300°C respectively, and the microhardness of Zn-1Sr and Zn-2Sr alloy materials after rolling at 250°C was 59 and 88. The microhardness of Zn-1Sr and Zn-2Sr alloy materials is 58 and 89 after rolling at 300 °C, which indicates that the rolling temperature has no great influence on the hardness of Zn-Sr base binary alloy, and can reduce the hardness of alloy materials. Biological test results show that the immersion corrosion rates (g·m-2·d-1) of extruded Zn-1Sr and Zn-2Sr alloys in Hank's solution are 4.281 and 5.374, respectively, which is consistent with the corrosion trend of as-cast alloys, and the corrosion rates of extruded Zn-1Sr and Zn-2Sr alloys are lower than those of as-cast alloys. The results show that the extrusion process enhances the corrosion resistance of as-cast Zn-1S and Zn-2Sr alloys. The immersion corrosion rates (g·m-2·d-1) of Zn-1Sr alloy rolled at 250°C, Zn-2Sr at 250°C, Zn-1Sr at 300°C and Zn-2Sr alloy rolled at 300°C in Hank's solution were 5.027, 5.934, 4.952 and 5.783, respectively. The corrosion trend is consistent with that of as-cast alloys, and the corrosion rate of rolled Zn-1Sr and Zn-2Sr alloys is lower than that of as-cast alloys, indicating that the rolling process enhances the corrosion resistance of as-cast Zn-1Sr and Zn-2Sr alloys [44].

4. Conclusion

In summary, the most important components of biodegradable ZN-based alloy materials are Mg and Ca, among which Mg can be widely used as cardiovascular scaffolds, Ca can play an active role in bone tissue healing, and Ag and Sr are still in their infancy and have not been widely used. The most important Zn-Mg and Zn-Mg-Ca biodegradable Zn-based alloys for biomedical purposes are Zn-Mg and Zn-Mg-Ca, in which binary Zn-Mg alloy is superior to Mg alloy and can also be used as orthopedic healing materials; terpolymer Zn-Mg-Ca alloy can promote the growth of new tissues and has good mechanical properties, other Zn-based alloys are still in the pilot stage as biodegradable materials for biomedical purposes and have not yet been mass-produced.

5. Research Prospects

A review of the elemental composition and typical alloys of biodegradable biomedical Zn-based alloys. Although biodegradable biomedical Zn alloys have made some achievements in the mechanical properties, biocompatibility and degradation rate of materials, they are still lacking in the structural and functional aspects of material design. That is, the degradation rate cannot be controlled while the mechanical properties are met, and vice versa. Therefore, the recent research directions of biodegradable biomedical Zn alloys in materials should include:

5.1. Alloy Element Composition Design

According to biological reports, the essential nutrient elements Ca, Sn, Fe and Sr can be added to the Zn-based alloy, and these elements should be further studied to develop new degradable biomedical Zn alloy materials.

5.2. Alloy Processing Process Design

According to reports related to material processing process, the microstructure of Zn-based alloy materials can be changed through plastic deformation process, the plastic deformation process. The usually includes extrusion, rolling (cold/hot), drawing and forging, therefore, the mechanical properties and corrosion resistance of Zn-based alloy materials can be improved through the use of plastic deformation process.

5.3. Preparation of Nanocrystalline Alloys

According to reports on the microstructure of materials, the microstructure of materials has a significant impact on mechanical properties and corrosion resistance. In general, the main reason is that a large number of grain boundaries appear after grain refinement, which leads to improved diffusion and easier to form a protective layer. At the same time, the increase of grain boundary area makes the distribution of impurities and pollutants more uniform.

5.4. Preparation of Composite Materials and Porous Materials

Composite materials with reinforcing phase metals (Fe, Mg, Ca, Ti, Zr, etc.) or non-metals (HA, ZnO, Al_2O_3, etc.) can further improve the mechanical properties, corrosion resistance and biocompatibility of degradable zinc-based alloy materials. At the same time, porous scaffolds provide the necessary support for cell proliferation, maintaining their functional and architectural differentiation to better define the final shape of the new bone.

In summary, a revolution is taking place in biodegradable biomedical metal materials. Zn-based alloy materials play an important role, and now only stay in the initial stage of research. Only through in-depth research on the degradation rate, biocompatibility and mechanical properties of Zn-based alloy materials, etc. It is possible to make biodegradable biomedical Zn alloy materials open a new chapter in the medical field.

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