Mini Review

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An investigation of the corrosion rate of Mg alloys in Hank's solution

Abstract

Magnesium alloys can be produced and formed using different techniques (casting, rolling, extrusion). Using the induction casting technique, magnesium alloys with biodegradable properties, good biocompatibility, and satisfactory mechanical properties are obtained, which are important to avoid the second surgical intervention to remove the implant.[1] In addition, the implant material must have bioactivity, allowing better bone anchorage and favoring the growth of bone tissue in its structure. The dimensional stability of the magnesium alloys is highly important to not collapse prematurely during regeneration.[2] The incorporation of alloying elements in magnesium promotes higher mechanical strength and improves corrosion resistance. In this work, two magnesium alloys, Mg-3.3Gd-0.2Zn-0.4Zr (wt%) (GK30) and Mg3.4Dy-0.2Zn-0.4Zr (wt%) (DK30), with different heat treatment conditions, were evaluated in Hank's solution, which simulates body fluids. The heat treatment conditions were selected according to the Group's previous results. Thus, alloy DK30 was treated at 180ºC for 60 h and 250ºC for 30 h, and alloy GK30, 180ºC for 100 h and 250ºC for 60 h. Hydrogen evolution and mass loss tests were carried out to determine the corrosion rate.

Keywords: biomaterials, magnesium alloy, corrosion rate, weight loss, evolution of hydrogen

Volume 11 Issue 1 - 2024

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Received: February 16, 2024 | **Published:** February 29, 2024

Introduction

With the increase in the population's life expectancy and the improvement in techniques for the development of biomaterials, there has been a significant expansion in the area of orthopedic implants. An example of advancement are bioadsorbable implants that are being developed to remain inside the body only for the time necessary for human tissue to recover, being naturally degraded over time.[2] Magnesium-based alloys are considered bioadsorbable biomaterials for use in temporary orthopedic implants, as they are materials that have a good biodegradability rate, good compatibility and a Young's modulus close to cortical bone, in addition to high resistance to injuries after adequate processing. These alloys are characterized by being light materials, due to the presence of magnesium, which is an element with low specific density (1.74 g/cm^3–2.0 g/cm^3).[2] And because the cation (Mg^{2+}) is the fourth most abundant mineral in the human body, it is classified as highly biocompatible, in addition to being essential for human health by Tian.

One of the challenges of applying magnesium-based alloys as bioadsorbable materials is their high corrosion rate, which leads the material to present undesirable characteristics, such as the loss of mechanical integrity in insufficient time for total tissue restoration by Vormann, generation of hydrogen gas which, if rapidly absorbed, leads to the balloon effect in vivo by Staiger in addition to causing a local change in pH by Witte. Possible solutions to control the handling rate of the magnesium alloy are the addition of an alloying element and the application of a polymeric coating.

Experimental

Methodology

The specimens were weighed before and after immersion tests on an analytical balance, Electronic Balance FA-2104N, BIOPRECISA, with an accuracy of 0.1 mg. The measurements of length, width, and thickness, of the specimen, were conducted with the aid of a digital caliper brand Mitutoyo, Digimatic Caliper model. The immersion test to evaluate corrosion by mass losstest was performed in HBSS solution (Hank's Balanced Solution), pH 7.45, and at 37 ºC±1ºC, kept in an oven model 520, FANEM brand. After the initial measurement, cleaning, and weighing, the specimen was placed individually in a Falcon tube, suspended by a nylon wire, taking care not to touch the walls of the same. The test followed the standard ASTM G31-72. The volume used of the HBSS solution in the Falcon tube was 50 ml. The specimen was evaluated in duplicate after 3 h, 6 h, 24 h, 48 h, and 72 h. After the test, the specimen was immersed in an aqueous solution containing 180 g/L of chromic acid for 1 min. Subsequently, the samples were cleaned with isopropyl alcohol, air-dried, and weighed. The hydrogen evolution test was performed in HBSS solution (Hank's Balanced Solution), pH 7.45, for exactly 72 h and at 37ºC±1ºC, maintained in a water bath. The proportion of HBSS solution to the surface area of the sample was approximately 600 ml to minimize the result of the pH change of the solution during the test. The hydrogen evolution test was performed in HBSS solution (Hank's Balanced Solution), pH 7.45, for exactly 72 h and at 37ºC±1ºC, maintained in a water bath. The proportion of HBSS solution to the surface area of the sample was approximately 600 ml to minimize the result of the pH change of the solution during the test. The generated hydrogen bubbles were collected using a funnel and an inverted burette containing the electrolyte solution, HBSS. The volume of hydrogen released, and the pH value of the solution were recorded at 24 h intervals. At the end, the specimen was carefully removed and immersed in an aqueous solution containing 180g/L of chromic acid for 1 min to remove the corrosion products present on the surface, then dried in cold air. The corrosion rate (Tc) was obtained according to Equation (1):

$$T_c = \frac{(K.W)}{(A.\ T\ .\ D)} \tag{1}$$

Where, K, constant to get the rate (mm/year); W, mass loss (grams); A, the area (cm^2); T, immersion time (hours); p, the density (g/cm^3)

Results and discussion

Alloys treated at 180ºC and laminated alloys have a high corrosion rate (Table 1), impairing their application as an implant. Comparing the specimens there was a greater increase in pH for the DK30 alloys compared to the GK30 alloys. This fact can be further explained by the high evolution rate of hydrogen. The pH increase was already expected due to Mg dissolution and OH- formation or H+ consumption, due to a higher corrosion rate in DK30 alloys.

Table 1 Comparison between the corrosion rates obtained by the mass loss test of DK 30 and GK30 alloys under different conditions, pH 7.45, temperature of 37°C±1°C

Specimen	Corrosion rate – 72 Hours (mm/year)
DK30 – 30 h – 250°C	4.40
DK30 – 60 h – 180°C	5.03
DK30 – Laminate	7.18
GK30 – 60 h – 250°C	2.97
GK30 – 100 h – 180°C	4.75
GK30 – Laminate	3.43

Table 2 shows the comparison of the hydrogen evolution results obtained after 72 h of immersion. It is noted that the only condition that presented a value below 0.01 $ml.cm^{-2}.day^{-1}$, an acceptable index for the human body,[1] and lower corrosion rate was the GK30 alloy heat treated at 250°C for a period of 60 h. It is possible to notice that the rolled alloys and those treated at 180ºC are highly corroded, have high values of hydrogen evolution, and show pitting corrosion. Thus, the GK 30 – 60 h – 250°C alloy was the only one that demonstrated potential application as a biomedical material for bioabsorbable implants.

Table 2 Comparison between the hydrogen evolution rates of DK 30 and GK30 alloys under different conditions, pH 7.45, temperature of 37°C±1°C

Specimen	Hydrogen gas evolution rate ($mL.cm^2.day^{-1}$)
DK30 – 30 h – 250°C	0.0124
DK60 – 60 h – 180°C	0.0739
DK30 – Laminate	0.0808
GK30 – 60 h – 250°C	0.0073
GK30 – 100 h – 180°C	0.0179
GK30 – Laminate	0.0211

Conclusion

The mass loss immersion tests revealed that, in general, the DK30 alloy showed a higher corrosion rate and a greater pH increase when compared to the GK30 alloy samples. In summary, the hydrogen evolution was intense for almost all conditions, a result that must be reflected since the proposal is for this material to be used for orthopedic implants. The GK 30 alloy treated at 250°C was the material that presented the best properties (lower corrosion rate and hydrogen evolution rate below the maximum limit for the human body), proving to be a promising biomedical material up until now.[3]

Acknowledgments

None.

Conflicts of interest

Authors declare that there is no conflict of interest.

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Citation: Silva TF, de T-Cury PLC, Tomachuk CR. An investigation of the corrosion rate of Mg alloys in Hank's solution. *J Appl Biotechnol Bioeng.* 2024;11(1):15–16. DOI: 10.15406/jabb.2024.11.00353