Design and Fabrication of Biocompatible Magnesium Alloy for Use in Cardiac Stent Application

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Abstract –The project is addressed towards the development of a magnesium alloy having properties desirable to be used as a cardiac stent keeping in consideration the economic parameters of our alloy with its performance. The selection of alloy is done on the basis of biocompatibility and which blend of elements can provide suitable corrosion resistance and properties required for a cardiac stent. Biocompatible magnesium alloy have not been developed to their full extent yet having the desired property of being bio-resorbable in the human body allowing angioplasty to be carried only once. This removes the dangers of thrombosis and restenosis that may occur in cardiac patients. The alloy is developed in arc button furnace ensuring strict environmental constraints are met. Mg-1wt%Nd-1wt%Mn-1wt%Zn was developed and its microstructure was studied. This analysis is done by SEM and EDX A comparative study is carried out with the magnesium alloys developed so far to authenticate the results of the alloy developed for cardiac stent.

Index Terms – Magnesium Alloy, Fabrication, Corrosion Resistance, Testing.

I. INTRODUCTION

Magnesium alloys previously had little or no role in the field of bio-materials. It's been a few years that magnesium alloys have been researched upon for use in cardiac stents. This is mainly due to its property of being bio-resorbable as well as bio-compatible. This aspect has led to countless experiments being performed, in-vitro as well as in-vivo, on magnesium alloys giving exceptional results. Thus, magnesium was proved as an excellent biodegradable stent material mainly due to its high susceptibility to corrosion [1]. This allows the stent to degrade inside the human body after performing its function. The time in which the stent degrades can be controlled by use of alloying elements. Consequently, it removes the problems like restenosis and thrombosis which are quite possible with use of stents made of titanium alloys or stainless steels [2].

The main challenge is to control the corrosion rate of magnesium alloy. This can be done by proper selection of alloying elements. In this case Magnesium was alloyed with Neodymium, Manganese and Zinc. The formation of alloy was done in Arc Button Furnace ensuring strict environmental constraints. Calcium was used as a guttering agent for oxygen. A few challenges were faced during the development phase of the alloy due to magnesium's very high oxidation potential. After successful development of a sample testing was done. The testing done included EDX and SEM.

II. PROCEDURE

A. Selection of Alloying Elements

The alloy selection was done based on availability, price and corrosion resistance. This was done by carrying thorough research on previously developed magnesium alloys and there results after testing. Moreover, effect of each element when alloyed with magnesium was studied and selection was mainly done on these basis.

B. Fabrication of Magnesium Alloy

After selection and ordering the elements fabrication was pursued. The fabrication had its complications mainly due to high flammability, vapor pressure and oxidation potential of magnesium itself. One of the reasons for this was the limitations of arc button furnace which had a single button capacity and no room for guttering agent placement. After a few unsuccessful attempts a graphite ring was designed and made to place calcium as guttering agent inside the furnace so that the oxidation of magnesium could be minimized. This yielded a much better result as our sample made was much better now due to its lesser oxidation and gave better results compared to previous samples made. Though magnesium alloys fabrication is normally done by vacuum casting we believe this is our projects novelty that we made it through arc button furnace. The problem being that with arc button furnace the vacuum generation was not significant as needed for fabrication of magnesium alloy which require ultra-high vacuum. Also to counter the vapor pressure of magnesium burning the pressure of Argon required was about 1.05 bars. The limitation was that the arc furnace valve opened at about 800 mbar pressure due to which ingress of oxygen was paramount.

C. Testing of Magnesium Alloy

Initially, the sample was tested in EDX for composition. The result was satisfactory considering losses due to burning though neodymium was not detected in the EDX due to unforeseen reasons. SEM and Micrograph analysis was also done to determine the microstructure of the sample developed. Comparison of SEM analysis was also done to determine the authenticity of alloy created. GAMRY was also done to determine the corrosion potential of the sample. In-vitro testing was not done due to non-availability of Hanks Solution and respective apparatus required.

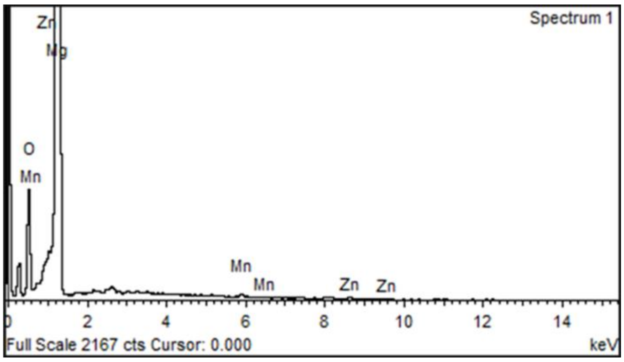
The sample had two regions as shown. This was because the sample thickness was lower. Grinding was done carefully and thus carbon deposit from graphite electrode of furnace can be seen at edges of the sample.

Figure 1 Sample after melting in ABF

III. RESULTS

A. EDX Analysis

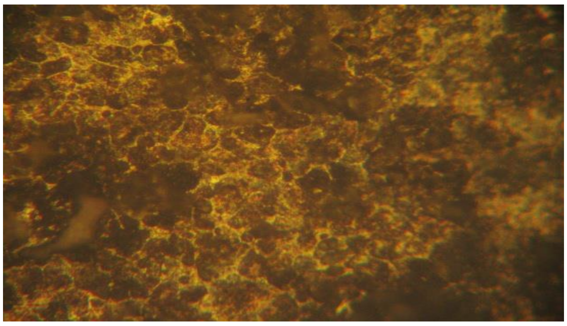
The composition of our sample was satisfactory keeping aside a few loses that were presumed. The only problem faced was that the composition of Neodymium was not detected. The composition originally was Mg-1wt%Nd-1wt%Mn-1wt%Zn. The result of EDX is as follows:



Element	Weight%	Atomic%
O K	7.28	11.50
Mg K	91.06	87.25
Mn K	0.75	0.51
Zn K	0.91	0.74
Totals	100.00	100.00

B. Micrograph and SEM Analysis

The SEM result was more than satisfactory after comparison with a previously developed biomedical magnesium alloy. Micrograph was done to check the grain size which ranged from 2-3. This meant a finer grain size and this was what we required for better ductility of the alloy. The micrograph and SEM comparison is shown below:



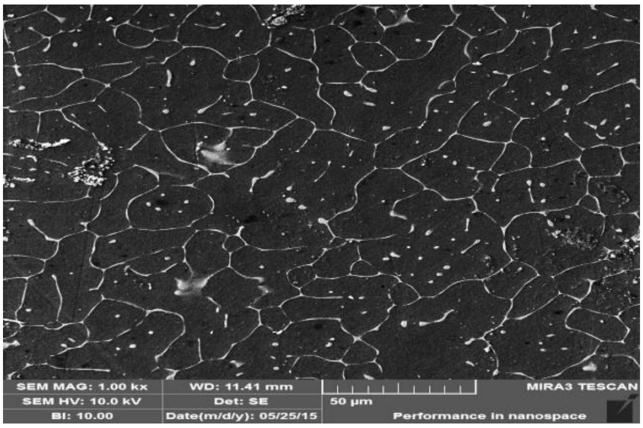


Figure 2 Magnesium alloy microstructure made in ABF

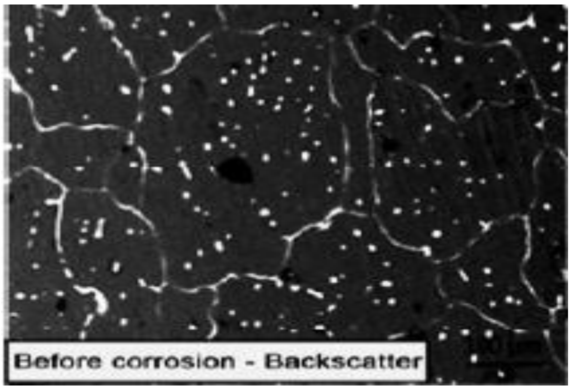


Figure 3 SEM of Magnesium alloy made in ABF

Figure 4 SEM of Magnesium alloy previously made

As seen from the SEM analysis the result obtained by us was much better and consisted of fewer nodular impurities which are critical to control corrosion. Moreover through comparison of EDX analysis it was found that our sample was oxidized much less compared to the other sample [3].

C. GAMRY – Potentiodynamic Scan

Figure 5 Linear Polarization Curve (Tafle Slope)

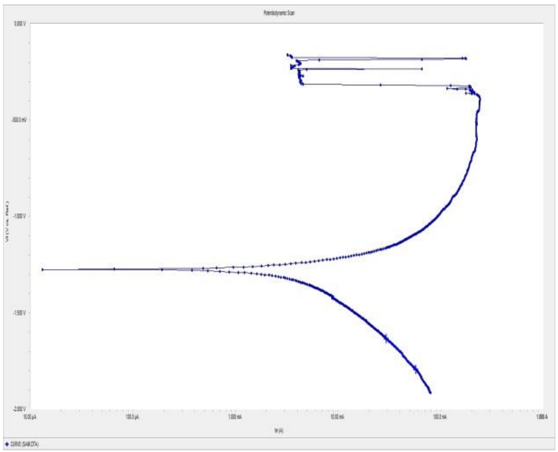


Figure 6 Potentiodynamic Polarization Curve

GAMRY testing was done in 3.5% NaCl Solution.

Values are as follows:

Anodic = 11.9×10^3 mills per year
Cathodic = 4.7×10^3 mills per year
E_{corr} =~ -1.25 V
I_{corr} =~ 30 mA

Corrosion rate was typically higher mainly due to the impurities and improper structure formation of sample. The sample started corroding at relatively lesser potentials. The structure was porous due to improper melting in the furnace and oxygen control was not significant resulting in a higher corrosion rate. Though the corrosion rate of magnesium alloy is supposed to be higher because it needs to get resorbed inside the human body, but the value of this result was much higher.

IV. DISCUSSION

Magnesium is a really good replaceable material to Titanium & Stainless Steel Stents due to their superior properties like better damping capacity and ductility as well as lower density compared to them. Sample oxidation has been a major problem while development of magnesium alloy. This was mainly due to constraints provided by the design of Arc Button Furnace. Results obtained were satisfactory but not up to the mark due to the limitations. Though, corrosion testing needs to be done further. For this we will use GAMRY. There was certainly room for improvement. Improvement parameters are given below:

1. Crucible redesign.
2. Guttering agent to control oxygen ingress.
3. Graphite Electrode replacement by tungsten.

V. CONCLUSION

It is certain that further research can be carried out in the field of Magnesium as Bio-implant material. Development of biodegradable magnesium implants has revolutionized the concept of metallic biomaterials. A qualified magnesium alloy implant should be one of matching corrosion rate with tissue healing rate, sufficient mechanical properties and acceptable biocompatibility. It is challenging but still promising to obtain such new kind of biodegradable metallic implants or devices. Mechanical properties strongly depend on the grain size, the solubility of alloying elements and the size, amount and distribution of the second phase. So the composition of the alloy, the heat-treatment and processing technique should be carefully designed. Once a perfect Mg alloy with desired properties is manufactured, low cost stent fabrication can be carried out.

VI. ACKNOWLEDGEMENT

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