Investigation of Biodrgradability of Wrought Mg-Ca-Mn Alloy as a Potential Material for Urological Applications

Fatemeh Akhlaghi[1], Ahmad Bahmani[2, *], Behzad Nayebi[1], Nader Parvin[1]
[1]Department of Materials and Metallurgical Engineering, Amirkabir University of Technology, Tehran, Iran
[2]Department of Advanced Materials and New Technologies, Iranian Research Organization for Science and Technology, Tehran, Iran
*a.bahmani@irost.ir

INTRODUCTION & AIM

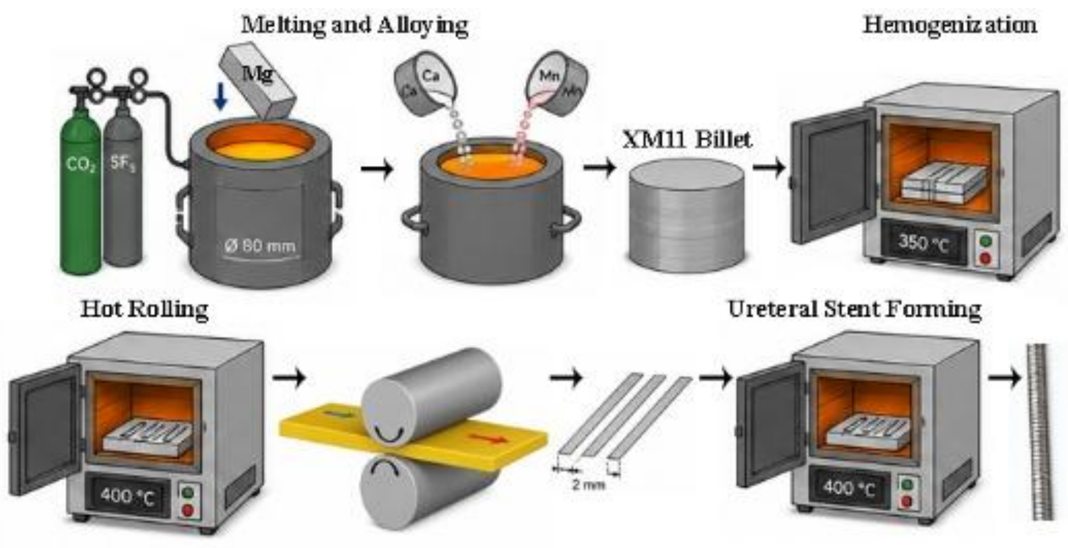
Ureteral stents are widely used after urological surgeries to maintain urine flow and prevent complications. Conventional polymeric stents are associated with encrustation, bacterial colonization, infection, and the need for secondary removal procedures [1]. Biodegradable stents offer a promising solution by eliminating the requirement for stent retrieval.

Magnesium (Mg) alloys are attractive biodegradable biomaterials due to their biocompatibility, mechanical properties, and controlled degradation in physiological environments [2]. However, their corrosion behavior must be optimized to ensure adequate mechanical performance during implantation. In this study, the biodegradation behavior of an Mg–Ca–Mn alloy was investigated to assess its suitability for biodegradable urological stent applications.

This study aims to evaluate the biodegradation performance of wrought Mg–Ca–Mn alloy for potential urological applications by examining its microstructure, corrosion behavior, and degradation characteristics in artificial urine (AU) solution in 37 °C environment.

METHOD

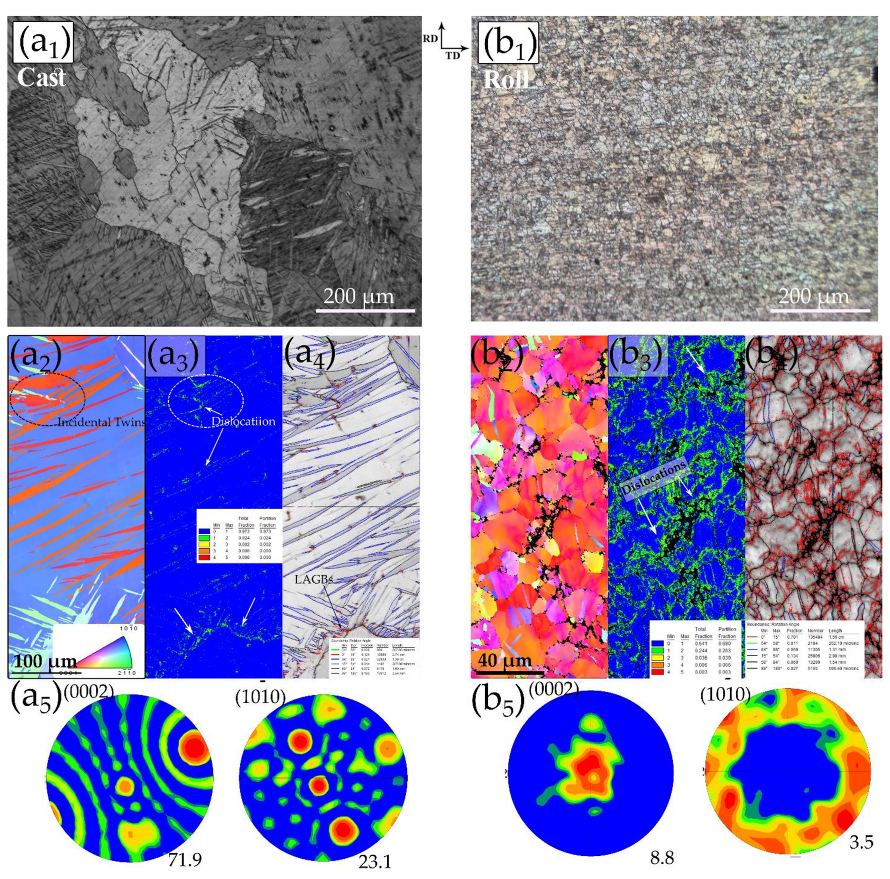
The Mg–Ca–Mn alloy was fabricated through casting, homogenization, and hot rolling. The resulting microstructure was characterized using OM, and XRD. Biodegradation performance was assessed by immersion testing in simulated urine solution, followed by corrosion and surface analyses.



RESULTS & DISCUSSION

Microstructure

- The as-cast sample exhibited a coarse and non-uniform grain structure with an average grain size of 200 ± 30 µm. Hot rolling significantly refined the microstructure, producing equiaxed with an average size of 17 ± 5 µm.
- Hot rolling substantially modified the microstructure and crystallographic texture through the formation of dislocations, low angle grain boundaries (LAGBs) and fine dynamic recrystallized (DRX) grains.
- The twin fraction decreased after rolling, while a basal texture developed. However, the overall texture intensity was reduced due to grain refinement, via tensile twins and DRX.

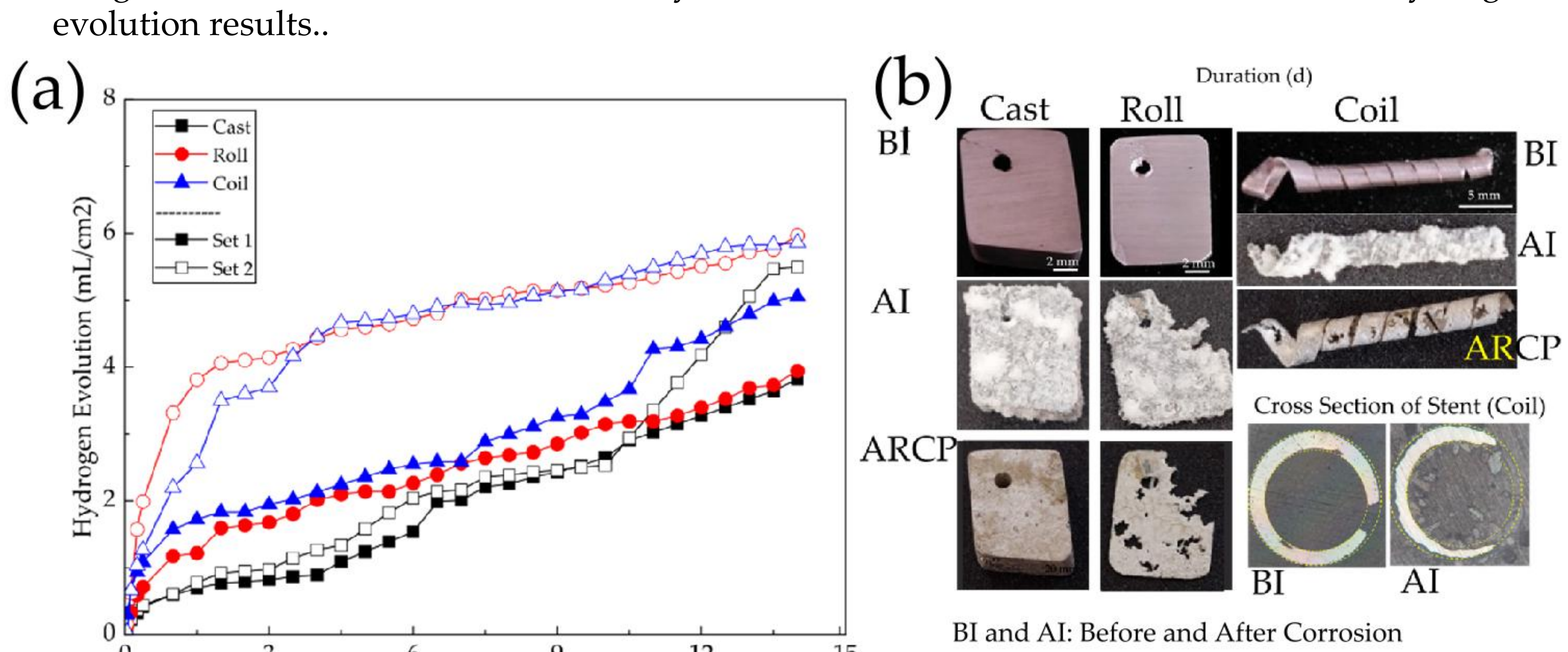


Degradation Behavior – Hydrogen Evolution and Weight Loss

- Mg degradation in AU produced $Mg(OH)_2$ and H_2 gas according to the following reaction.:

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2(g)$$

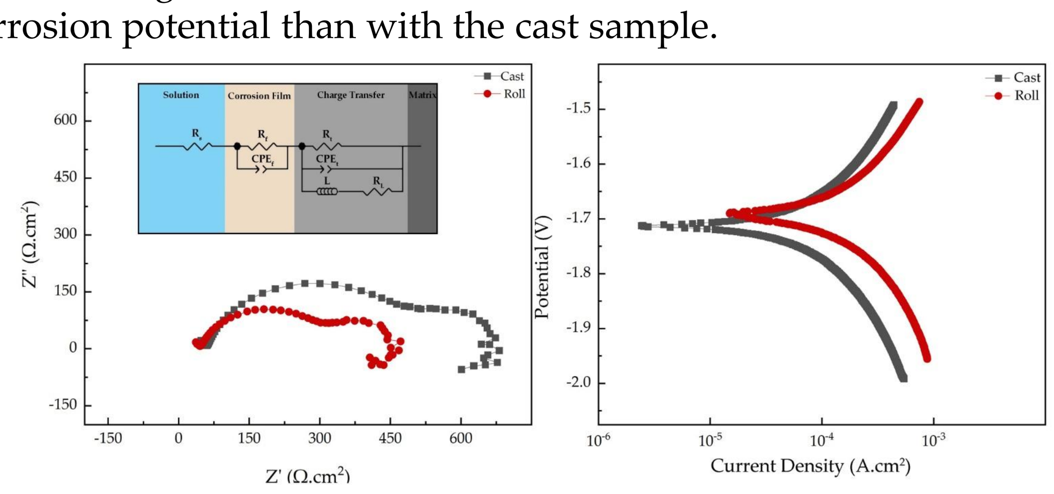
- All samples exhibited a high initial corrosion rate during the first 48 h, due to direct exposure of the bare metal surface. The rolled alloy showed a higher initial corrosion rate than the cast alloy. The corrosion rates decreased with immersion time as a protective surface layer formed and stabilized on the alloy surface.
- Weight loss measurement after 14 days of immersion were consistent with the hydrogen evolution results..



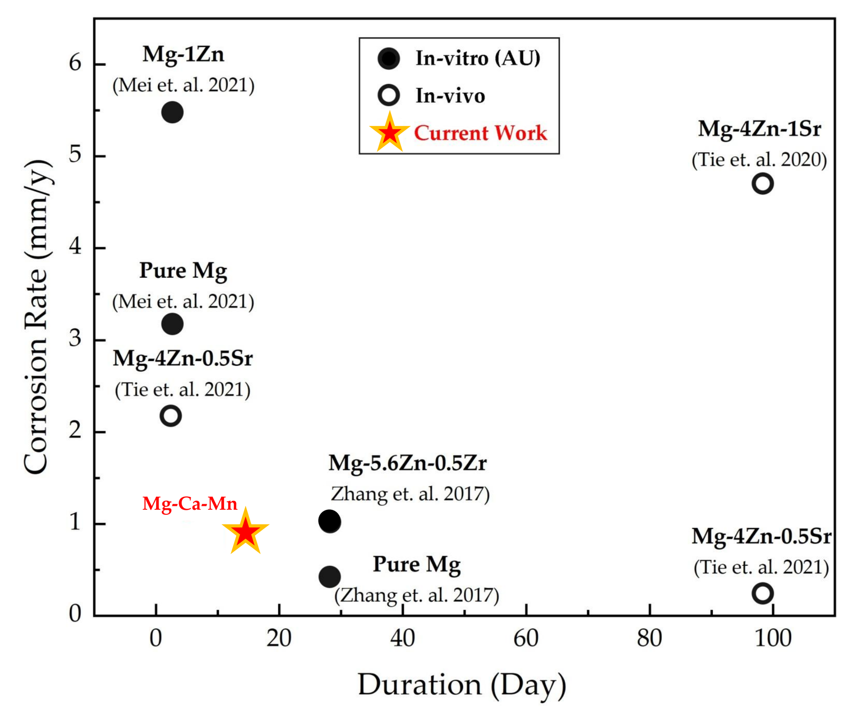
BI and AI: Before and After Corrosion
ARCP: After Removing Corrosion Products

Degradation Behavior - Electrochemistry

- As shown in the Nyquist plot below, two capacitive loops and one inductive loop were observed for both samples, corresponding to the surface film and the metal/electrolyte interface. The higher initial degradation rate of the rolled sample is attributed to its increased dislocation density and grain boundary fraction. However, the overall corrosion behavior of all samples became similar over longer immersion periods. This difference arises because electrochemical measurements reflect the early stages of degradation, whereas hydrogen evolution and weight loss tests represent long-term corrosion behavior. In addition, the rolled sample exhibited a more noble corrosion potential than with the cast sample.



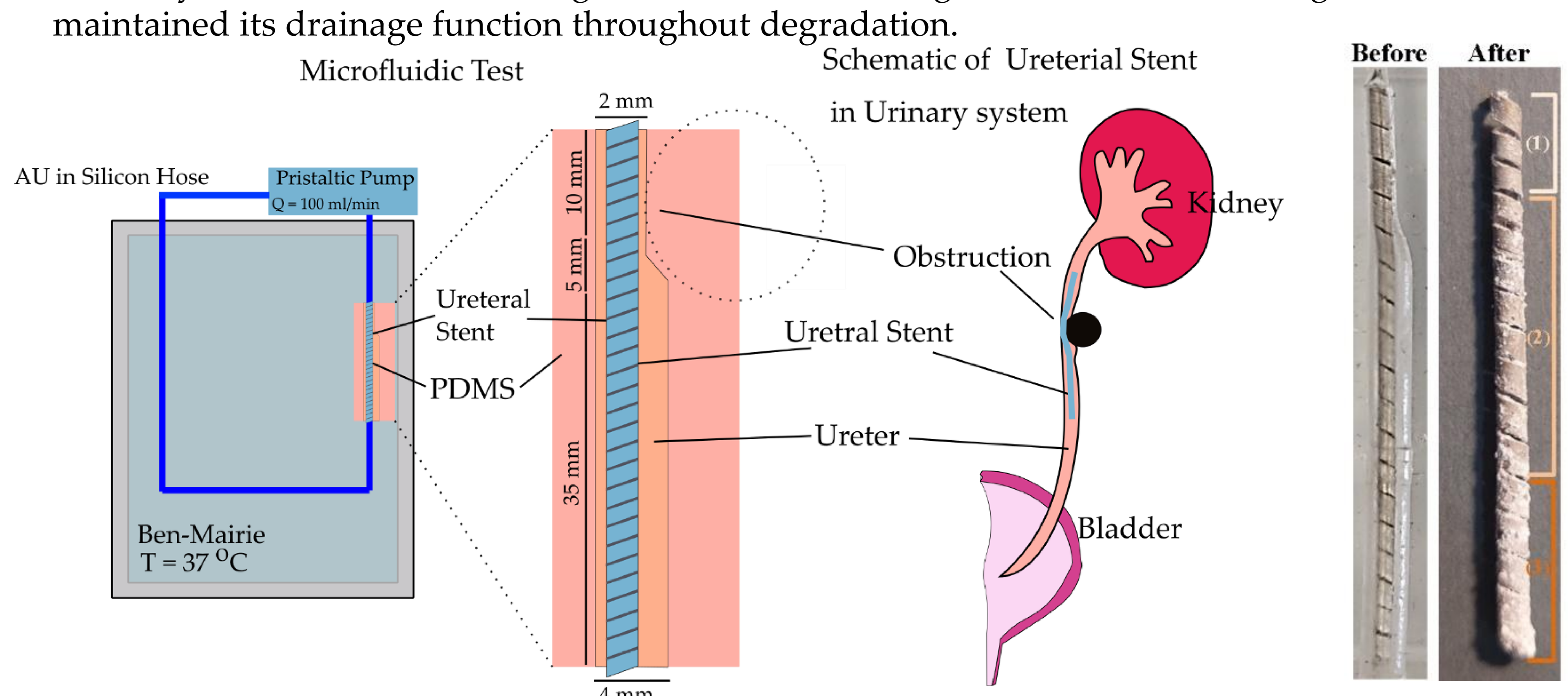
Sample	Ev. Hydrogen (ml.cm^{-2})	P_H (mm.y^{-1})	Lost Mass (mg.cm^{-2}.d^{-1})	P_w (mm.y^{-1})	i_{corr} (µm.cm^{-2})	E_{corr} (V)	P_i (mm.y^{-1})
As-cast	4.02 ± 0.21	0.64 ± 0.07	0.53 ± 0.08	1.11 ± 0.18	6.07×10^{-5}	-1.712	1.387
Rolled	6.07 ± 0.10	0.89 ± 0.01	0.77 ± 0.00	1.63 ± 0.01	10.51×10^{-5}	-1.639	2.402
Coiled	4.87 ± 0.30	0.70 ± 0.07	0.61 ± 0.05	1.28 ± 0.11	-	-	-



- Comparison between current results with similar studies demonstrates that the present alloy achieves a controlled and moderate corrosion rate over 14 days of in vitro immersion, highlighting its potential for biodegradable stent applications.

Dynamic Corrosion Test

- The schematic illustration below shows the dynamic corrosion setup. The stent was tested in a PDMS urinary tract model at 37 °C, under artificial urine (AU) flow (600 ml/min, 30 s every 6 h) for 7 days. No urine-flow blockage was observed during the test, demonstrating that the stent maintained its drainage function throughout degradation.



CONCLUSIONS

- Hot rolling successfully refined the microstructure of the XM11 alloy, resulting in significant grain refinement and suitable corrosion behavior.
- The XM11 alloy exhibited a high initial corrosion rate that decreased over time due to protective oxide layer formation, with weight loss and hydrogen evolution tests showing consistent degradation trends.
- The degradation rate proved the complete degradation within 60 days, indicating its potential as an alternative to conventional polymeric stents.
- Dynamic corrosion testing confirmed that the XM11 stent retained its urine drainage function during biodegradation, suggesting its ability to provide continuous urinary support while gradually resorbing in the body.

REFERENCES/ACKNOWLEDGMENT

[1] N. Tomer, E. Garden, A. Small, M.J.T.J.o.u. Palese, Ureteral stent encrustation: epidemiology, pathophysiology, management and current technology, 205(1) (2021) 68-77.
[2] A. Mosayyebi, C. Manes, D. Carugo, B.K.J.C.u.r. Somani, Advances in ureteral stent design and materials, 19 (2018) 1-9.
[3] A. Bahmani, S. Arthanari, K.S.J.J.o.M. Shin, Alloys, Formulation of corrosion rate of magnesium alloys using microstructural parameters, 8(1) (2020) 134-149.
[4] D. Tie, R. Guan, H. Liu, M. Chen, S.A. Ulasevich, E.V. Skorb, P. Holt-Torres, X. Lu, N.J.J.o.M. Hort, Alloys, In vivo degradability and biocompatibility of a rheo-formed Mg–Zn–Sr alloy for ureteral implantation, 10(6) (2022) 1631-1639.

ACKNOWLEDGMENT: The authors acknowledge Iranian Research Organization for Science and Technology for the support of the project through the contract number of 1012003003 and Amir Kabir University of Technology.