Wire – Arc Additive Manufacturing (WAAM) of Zn for Biodegradable Metallic Implants

Rishabh Soni[1], Suyog Jhavar[2], Suhela Tyeb[1], Saurabh Kumar Gupta[1], Satyam Suwas[1], Kaushik Chattterjee[1]

[1]Department of Materials Engineering, Indian Institute of Science, Bangalore, India [2]School of Mechanical Engineering, VIT–AP University, Amravati, India

Introduction

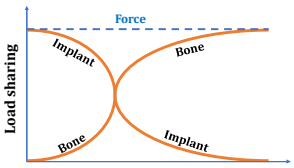
- Currently used permanent implants
  - Ti and Ti alloys
  - Co-Cr alloys
  - Stainless steels





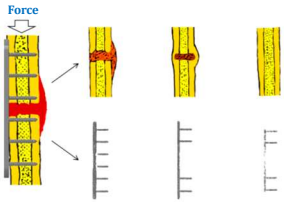


- Biodegradable metals are a new class of biometals that can be used as a potential replacement for implant materials to overcome the burden of secondary surgeries and its related costs



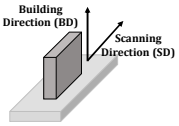
- Potential biodegradable metallic materials
  - Fe and Fe alloys
  - Zn and Zn alloys
  - Mg and Mg alloys





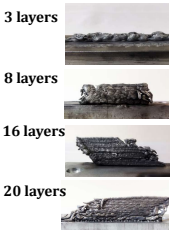
Setup and processing

- Process parameters variation
  - Heat input (arc power in watts)
  - Travel speed (TS in mm/min)
  - Wire feed rate (WFR in mm/min)
  - Standoff distance (in mm)



WAAM-TIG setup

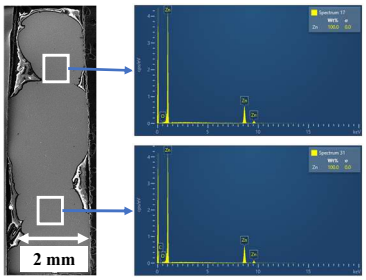


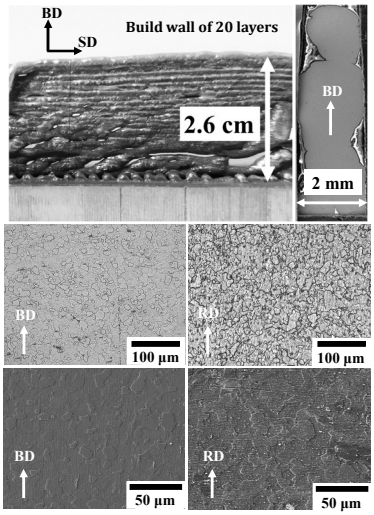


Microstructural characterization

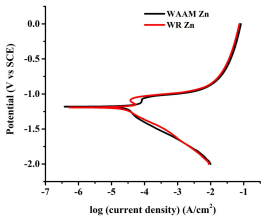
- Optical and scanning electron microscopic images suggest that deposited layers are dense with little to no evaporated voids
- Elemental examination through EDS shows that there is no contamination of oxygen and other elements
- The grain sizes and hence the microhardness of the wrought (WR) and WAAM parts are similar

Sample	Grain Size	Microhardness
WR Zn	11 ± 4 µm	35 ± 2 HV0.3
WAAM Zn	14 ± 5 µm	41 ± 1 HV0.3





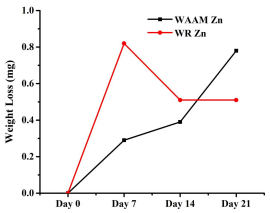
Biocorrosion measurements (SBF) of the WR and WAAM samples



- Tafel extrapolation method was used to assess the corrosion behavior of the samples.
- Similar single-phase grain morphology and hardness values of the samples result in similar corrosion behavior of the alloys.
- Corrosion rates calculated through Icorr and Ecorr values to be 0.3±0.1 mmpy and 0.45±0.2 mmpy for WR-Zn and WAAM-Zn samples, respectively.

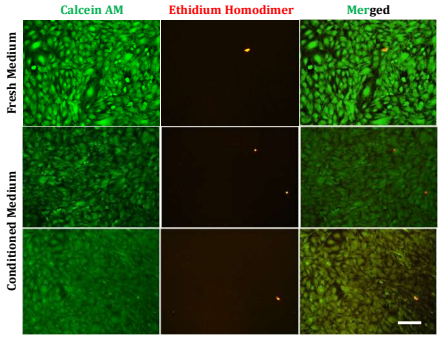
Biodegradation studies (SBF) of the WR and WAAM samples

- Weight loss measurements were done to assess the degradation rates of the samples for different time durations.
- Marginally higher weight loss was observed for WAAM-Zn than WR-Zn.

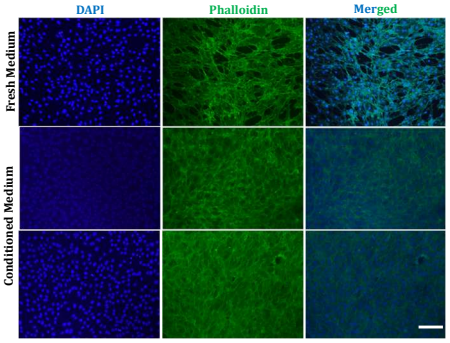


Biological characterization

Live/dead staining of MC3T3-E1 cells, performed after 48h of treatment



Nucleus and actin filament staining of the 48h-treated cells



Conclusion

- Optimization of the process parameters for WAAM (TIG) of Zn

Arc Power	Wire Feed Rate	Travel Speed	Standoff Distance
400 W	160 mm/min	120 mm/min	5 mm

- Corrosion and degradation rates are comparable.
- Cells are alive and viable in both the media with degradation products (i.e. WAAM and WR) which shows the cytocompatibility of the metals.

Acknowledgement

- The authors acknowledge the access to equipment at the Department of Materials Engineering, Indian Institute of Science, Bangalore, India.
- This research was funded by the Science and Engineering Research Board (SERB) of the Government of India (CRG/2021/006468).

References

1. Zheng, Y.F.; Gu, X.N.; Witte, F. Biodegradable Metals. Mater. Sci. Eng. R Rep. 2014, 77, 1–34
2. Salmi, M. Additive Manufacturing Processes in Medical Applications. Materials 2021, 14, 191
3. Amukarimi S, Mozafari M. Biodegradable magnesium-based biomaterials: An overview of challenges and opportunities. MedComm. 2021;2:123–144
4. **Soni, R.**; Jhavar, S.; Tyeb, S.; Gupta, S.K.; Suwas, S.; Chatterjee, K. Wire Arc Additive Manufacturing of Zinc as a Degradable Metallic Biomaterial. J. Funct. Biomater. 2022, 13, 212