Proceedings of the 9th World Congress on Electrical Engineering and Computer Systems and Sciences (EECSS'23)
Brunel University, London, United Kingdom – August 03-05, 2023
Paper No. ICBES 144
DOI: 10.11159/icbes23.144

Effects of Tapered-Strut Design on Corrosion Resistance for Biodegradable Magnesium Stents

Li-Han Lin and Hao-Ming Hsiao*
Department of Mechanical Engineering, National Taiwan University
No. 1, Sec. 4, Roosevelt Rd., Da'an Dist., Taipei, 106319, Taipei City, Taiwan
D09522010@g.ntu.edu.tw; hmhsiao@ntu.edu.tw

Extended Abstract

Heart disease is the leading cause of death worldwide, with the drug-eluting stents (DES) being the gold standard for the coronary intervention. Despite the DES success, the holy grail of the coronary intervention has always been a device that could disappear over time, leaving the patient's arteries free of metal scaffolds. The biodegradable magnesium stent has emerged as an excellent alternative for cardiovascular disease due to its unique properties and drawn wide attention in the medical field in recent years. Its degradation rate is controlled by several corrosion mechanisms, including pitting, filiform, stress corrosion, etc., and has to be properly managed to reach the optimal balance for vessel healing. The major strategy for modulating corrosion is mainly focused on the surface modification of the magnesium stent to prolong its degradation time.

Stress corrosion is a type of corrosion that occurs due to a simultaneously combined action of applied stresses in a stimulating corrosive environment [1]. Stress concentration in stents is a major issue for magnesium stents because it often triggers severe stress corrosion and breaks down the structural integrity. In this paper, a simple yet powerful tapered-strut design concept for the enhancement of corrosion resistance was proposed. This concept is to shift the stress concentration away from the crowns and re-distribute the stresses along the stress-free struts by tapering the strut width. This novel concept was able to enhance the stent fatigue life by several times in our previous studies [2-3].

Finite element analysis (FEA, ABAQUS) and computational fluid dynamics (CFD, ANSYS) were performed to evaluate the stent mechanical integrity and hemodynamic behaviour under various conditions consistent with the current practice. Stent prototypes were manufactured in-house by laser, followed by the validation of bench tests for proof of concept. Flow-induced shear stress (FISS) was considered because corrosion could be accelerated by the increased mass transfer and mechanical forces [4]. The wall shear stress (WSS) was also an important indicator, as higher WSS led to concentrated corrosion morphology while lower WSS induced severe restenosis [5].

Both simulation and experiment were conducted on the tapered-strut stent design with 20% width reduction at the midpoint of the strut. FEA results show that the maximum stresses at crowns decreased significantly as the strut was tapered, effectively reducing the stress concentration. CFD results show that the tapered-strut design also induced lower flow velocity and WSS, suggesting better corrosion resistance based on the conclusions from Ref. [4]. Bench tests indeed demonstrates that the taper-strut design had slower corrosion rate when compared to its non-tapered counterpart in both static and dynamic flow environments, consistent with our FEA and CFD predictions. This design concept has a great potential in improving corrosion resistance and points to an important direction for future stent designers to follow.

References

[1] R. Wang, Z. Yuan, Q. Li, B. Yang, and H. Zuo, "Damage evolution of biodegradable magnesium alloy stent based on configurational forces," *Journal of Biomechanics*, vol. 122(9), 110443, 2021
[2] L. H. Lin, K. L. Ho, Y. M. Jian, K. H. Chiang, and H. M, Hsiao, "Effect of tapered-strut design on fatigue life enhancement of peripheral stents," *Bioengineering*, vol. 10(4), no. 443, 2023.
[3] H. M. Hsiao and M. T. Yin, "An intriguing design concept to enhance the pulsative fatigue life of self-expanding stents," *Biomed Microdevices*, vol. 16, pp. 133-141, 2014.
[4] J. Wang, V. Giridharan, V. Shanov, Z. Xu, B. Collins, L. White, Y. Jang, J. Sankar, N. Huang, and Y. Yun, "Flow-induced corrosion behaviour of absorbable magnesium-based stents," *Acta Biomaterialia*, vol. 10(12), pp. 5213-5223, 2014.
[5] D. Liu, S. Hu, X. Yin, J. Liu, Z. Jia, and Q. Li, "Degradation mechanism of magnesium alloy stent under simulated human micro-stress environment," *Materials Science & Engineering C*, vol. 84, pp. 263-270, 2018.