

Recycling High-Value Metal Powders for Acidic Water Splitting: A Circular Economy Approach to Metal Additive Manufacturing

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Problem Statement:

The rapid growth of the metal additive manufacturing (AM) industry has resulted in the early disposal of high-value, specialty alloy powders due to oxidation. This poses a significant challenge, as the industry is estimated to have a revenue of over \$11 billion by 2024. Additionally, the current electrode technology for water splitting requires purified and distilled water, making it difficult to use in areas where clean water is scarce. This issue is further compounded when using acidic water due to the lack of industrially viable electrodes. Therefore, finding a cost-effective and efficient method to reuse specialty alloy powders and developing industrially viable electrodes for impure water sources are crucial challenges for their respective industries.

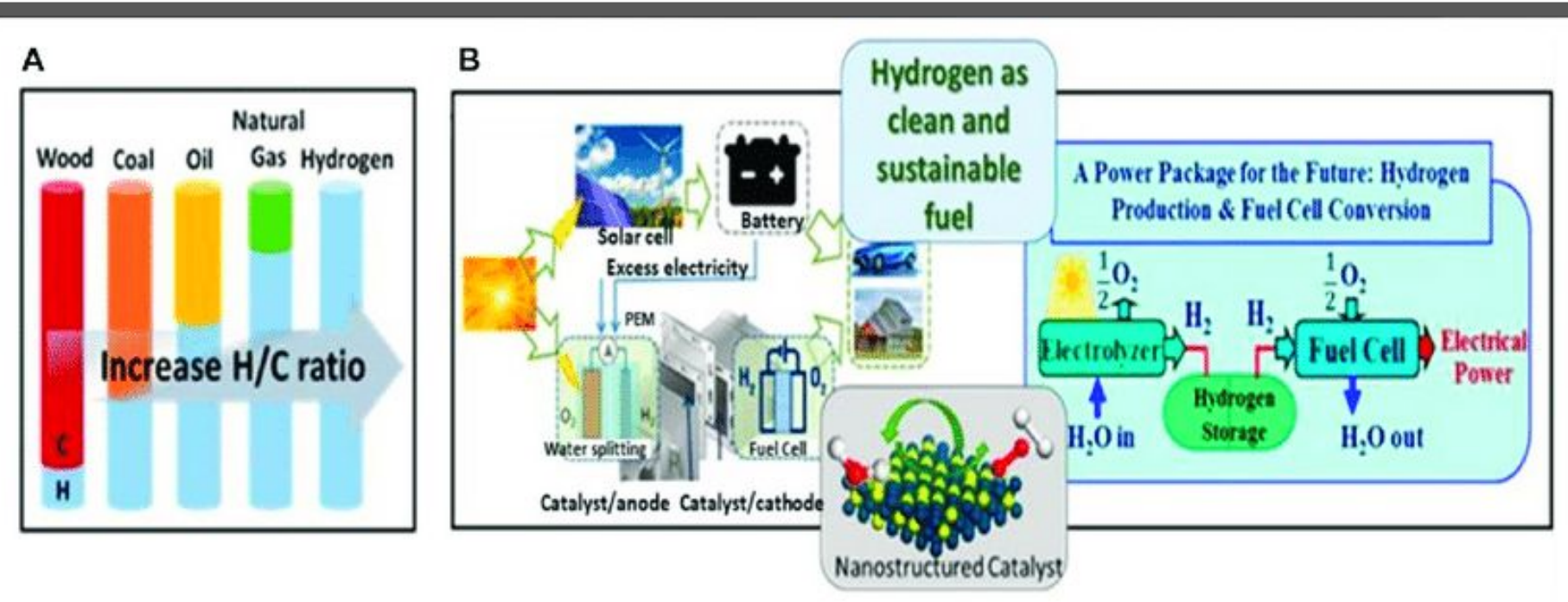


Figure 1. a) Comparison of hydrogen to carbon ratios for various fuel sources, highlighting the potential of hydrogen as a clean energy source with a ratio of 4:1. b) Dual cell schematic demonstrating its ability to operate as an electrolysis water splitting cell, generating hydrogen from solar energy, and as a fuel cell, converting hydrogen into electricity. This innovative technology has the potential to provide a sustainable and renewable energy source for the future. Graphs from S. Wang, et al., Nano Convergence.1

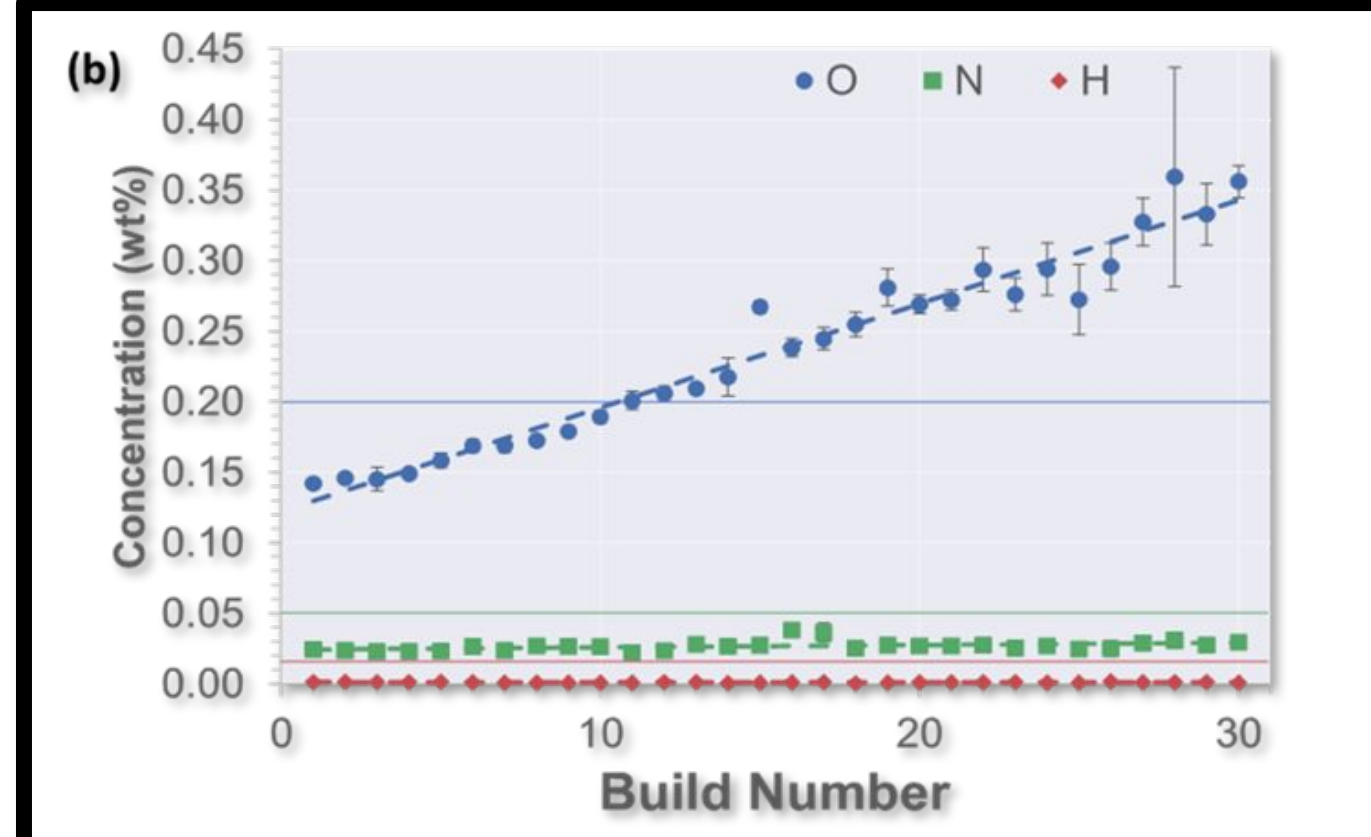


Figure 2. Repeated uses/builds raise concentration of oxygen in Ti64 powders. In comparison to rather little variation of metallic and other non-metallic compositions, linear increase of oxygen is evident. Graphs from M. Ramulu, et al., Materialia.



Figure 3. Berkely Pit, Butte, Montana. Mining activities that expose sulfur to rainwater create acid water drainage. This large source of undesired acidic water could serve as a source for water splitting for hydrogen production.

Approach:

In this study, used Ti-Al6-V4 powder was sintered into electrodes for use in water splitting. Multiple electrode configurations were tested in an electrochemical cell, in conjunction with platinum and gold electrodes, to determine their efficiency in terms of current generation, catalytic effect, and long-term stability. The electrodes were then imaged using a scanning electron microscope and X-ray diffraction, and the solution in which the reaction took place was characterized at intervals using infrared spectroscopy.

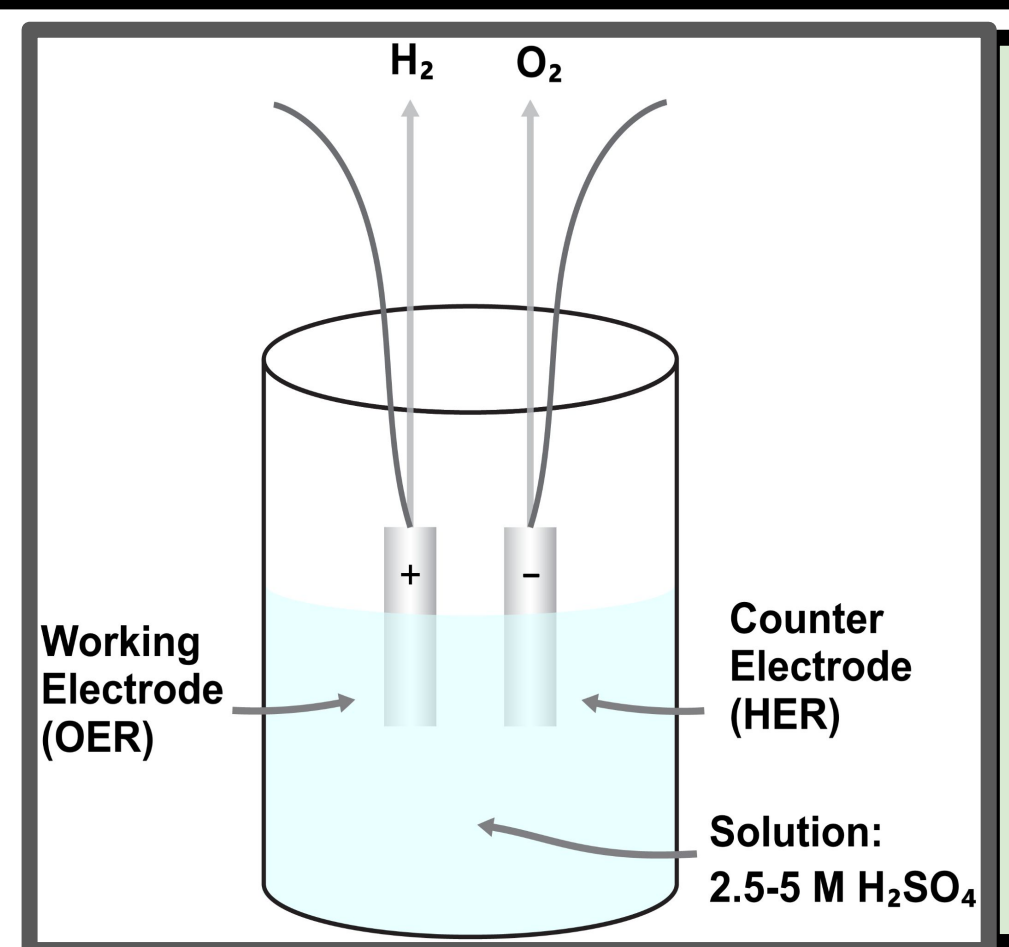


Figure 4. Electrochemical Cell Setup: The electrodes, including gold, platinum, and titanium alloy, were partially immersed in a 2.5-5 M sulfuric acid solution and configured in multiple arrangements. The positively biased electrode generated hydrogen, while the negatively biased electrode produced oxygen through the process of water splitting.

Results:

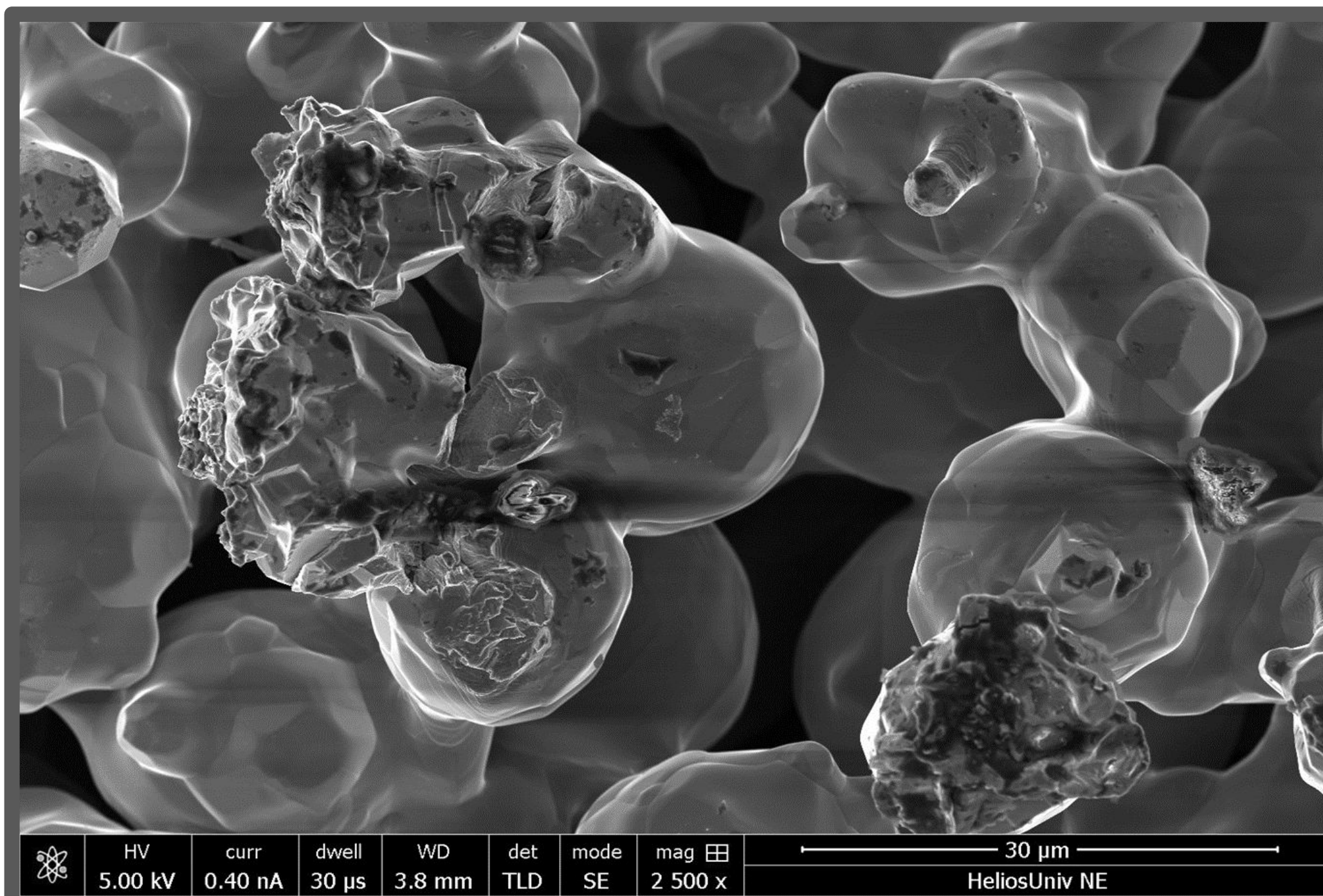


Figure 5. The titanium alloy electrodes were sintered at a low temperature to increase their porosity, resulting in a larger reaction surface area. Notably, these electrodes exhibit a remarkably low resistance, measuring at less than 0.1 Ω, indicating their potential for efficient electron transfer in electrochemical reactions.

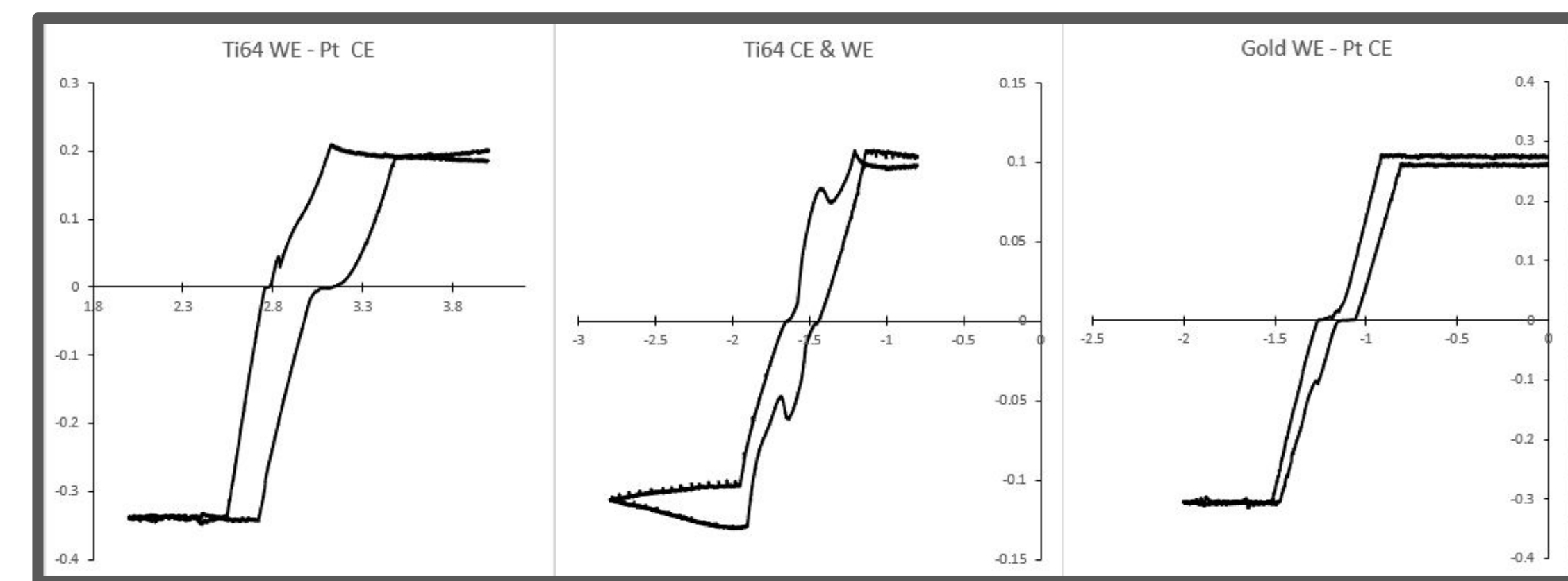


Figure 6. The plots depict cyclic voltammetry measurements of various electrode combinations in sulfuric acid with pH 2. In condition a), the highest overall current of ~.34 A was obtained with titanium (Ti) facilitating hydrogen evolution reaction (HER) and platinum (Pt) facilitating oxygen evolution reaction (OER). In condition b), the presence of secondary peaks in the cyclic voltammogram suggests the occurrence of additional reaction mechanisms and possible catalytic effects.

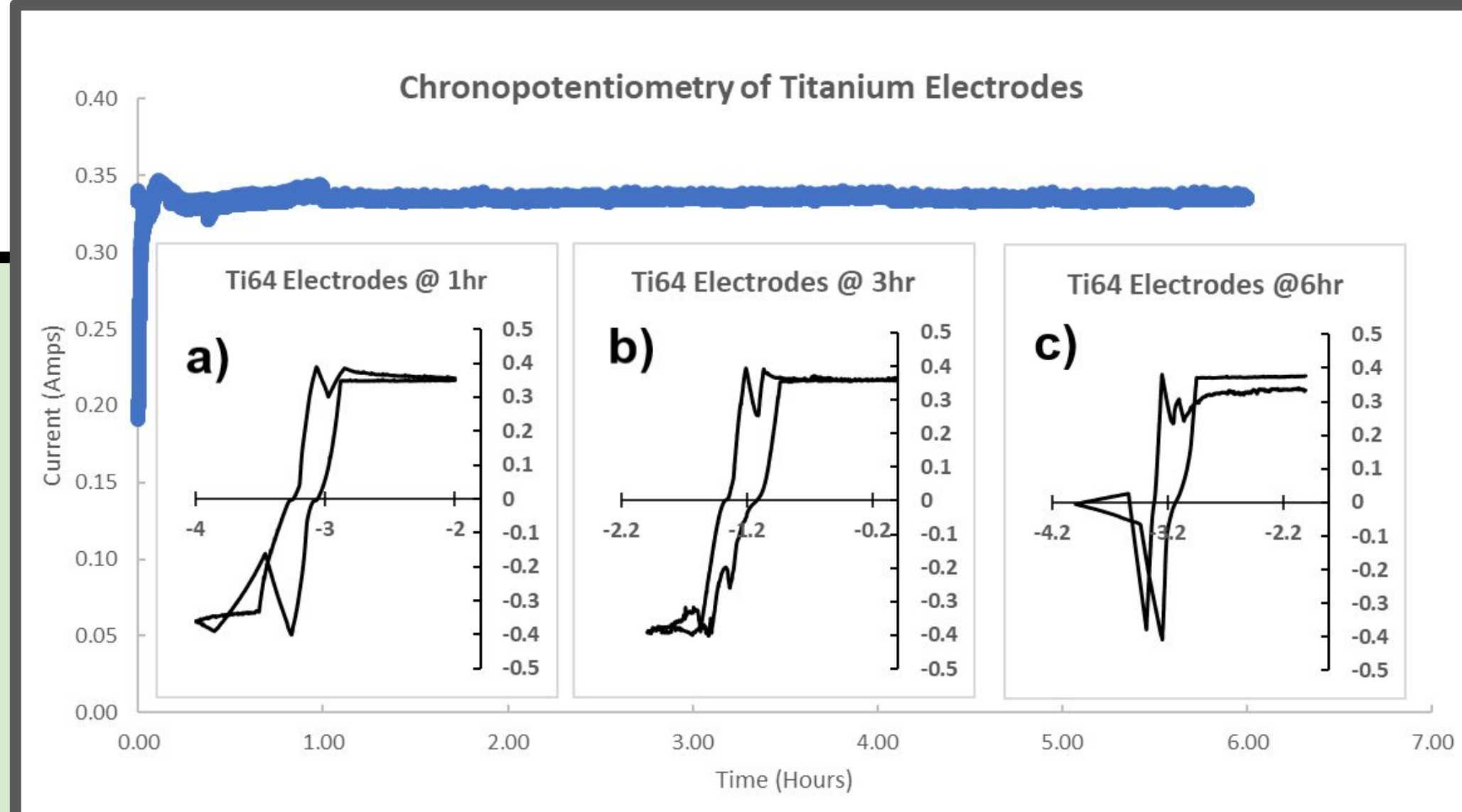
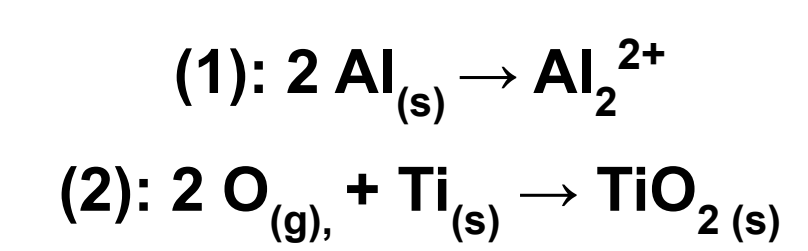


Figure 7. The cyclic voltammograms plots (a,b,c) display measurements of titanium alloy electrodes taken at regular intervals over a 6-hour steady voltage reaction in a 2.5 M sulfuric acid solution. Notably, the overpotential decreases as the reaction progresses, indicating improved efficiency. Additionally, the emergence of multiple, distinct peaks in the plots suggests the development of new reaction mechanisms. Despite the harsh acidic conditions, the current for the reaction remained constant at approximately 0.35 A, highlighting the high stability of the titanium alloy electrodes under these conditions.

Conclusion:

The titanium alloy electrodes showed high stability in strongly acidic conditions of up to 5 M sulfuric acid, far beyond the standard acidity currently used in PEM electrolysis (<1 M). The used alloy contains high levels of oxides from AM processes that may function as a cheaper alternative to expensive rare earth metal catalysts. Two mechanisms are proposed for the changes in the CV plots. (1) The OER electrode experiences oxide layer growth during the long term reaction that increases the catalytic effect, shown by the reduced overpotential as the reaction continues. (2) On the OER electrode, aluminium atoms from the alloy are dissolved in solution. This reaction is thermodynamically favored in the OER environment and shifts the center of the CV plots to a negative value. The electrodes show potential to function as a corrosion-resistant alternative to expensive rare earth catalysts currently used in acidic water splitting. There is also potential for operation in impure water sources.



Acknowledgement:

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