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| Projects Final report | | |
| **Call round: - 2** | | |
| **Project Title: Ultrasonic stimulation and degradation monitoring of electrochemical processes** | | |
| **PI:** Dr. Frederic Cegla | **Research Organisation:**  **Imperial College London** | |
| **Department: Mechanical Engineering** | **Start Date: 13/02/2023** | **Duration 12/06/2023** |
| **Cost of award (80%):**  £46,134 | **Value of co-investment:** N/A  **In kind:** N/A  **Cash:** N/A | |
| **Co-I and associated RO:**  Dr. Yifeng Zhang | **Acoustic Research themes:**  Acoustics for manufacturing and industry, Acoustics for understanding of climate change, Sustainable acoustic solutions,  Acoustic streaming, high power ultrasonics, ultrasonic monitoring | |
| **Collaborations & Partnerships involved in project:** Tell us about bi-lateral or multi-lateral partnerships/participation by the PI or research team in a network, consortium, multi-centre study  This was a pilot experimental feasibility study. Most of the time and budget was spent building a setup in the laboratory and to gather experimental results. Nonetheless, we had interactions and useful discussions with researchers from the applied mathematics department at the University of Liverpool and from the chemistry department at University College London. We have also discussed the work with researchers from the University of Loughborough and the University of Oxford. | | |
| **Project Partners** | | |
| **Value and details of in-kind co-investment: -**  **N/A** | **Value and details of cash co-investment: -**  **N/A** | |
| **Summary:** The ultimate aim of this research was to demonstrate the feasibility of using ultrasonic stimulation to affect the electrochemical processes at electrode surfaces in energy storage systems. A symmetric aqueous Zinc system was chosen for demonstrations and a test cell that allowed ultrasonic in sonification during electrochemical cycling was built. Then a range of experiments were conducted to demonstrate the effect of ultrasound on the potentio-dynamic response of the system. The left image (figure 1 A) shows a schematic of the experimental setup that was built: two Zinc strips were used as electrode and immersed in the electrolyte, a multipurpose Potentiostat / Galvanostat / ZRA (Zero Resistance Ammeter) electrical source that could either apply a constant voltage or impose a constant current between the electrodes was connected in between both strips, a high power ~1.4MHz resonant piezo electric transducer was placed below the strips and a microscope was installed to observe the formation of dendrite in between the electrodes. The plot (in figure 1B) shows a the typically observed effect of ultrasonic stimulation on the potential difference across the two electrodes shortly after a constant current is applied across the two electrodes. By introducing ultrasonic agitation (from beneath), acoustic streaming is initiated which enhances ion transport in the electrolyte, a clear reduction in overpotential can be observed, suggesting lower ‘resistance’ and better charge transport between the two electrodes. The effect on dendrite suppression can also be observed from synchronised microscopic images see figure 2B). We are currently writing up the work and intend to submit it to the journal of electrochemistry communications for dissemination.   |  | | --- | | A)B) | | Figure 1 A) Schematic of experimental setup B) Voltage across zinc electrodes after constant current density of j=6.5mA/cm2 was applied across the electrodes | | | |
| **Objectives:**  Key deliverables and objectives of the research were:   1. to acquire measurement data that links acoustic streaming to electrochemical reaction rates and that shows the prevention of degradation such as dendrite growth, 2. to published outcomes in high-quality energy/acoustics journals, 3. to gather pilot data that will help prepare proposals for potential funding agencies and industrial partners. | | |
| **Outcomes/Impact\*:**  We have constructed a new measurement rig and successfully acquired measurement data that shows the effect of ultrasonic stimulation on the electro-chemical processes. The figure 2A) below shows a photograph of the rig with the electrical equipment in the background and the microscope and vessel containing the Zinc electrodes in the foreground, the high power ultrasound transducer is not visible as it is located at the bottom of the vessel.   |  | | --- | | A)  B) | | Figure 2 A) photograph of the rig that was constructed B) Microscope images of the two zinc strips |   A campaign of many measurements was performed. The measurement protocol always involved preparing an electrolyte, Placing the Zinc electrodes into the electrolyte, observing the system at rest, then applying a current across the two Zinc electrodes for 5 minutes and measuring the resulting potential across the electrodes and observing the dendrite growth on the surface. The applied current density j=6.5mA/cm2 was chosen so that it is above the limiting current for dendrite formation, meaning that the boundary layer on the surface of the Zinc electrode becomes depleted of Zinc ions so as to promote non-uniform deposition in form of Zinc dendrites. Our theory was that the application of the ultrasound then induced acoustic streaming and enhances the transport of Zinc ions into the depleted layer so that less non-uniform deposition takes place. This theory was experimentally confirmed by observation:  Figure 2 B shows a hugely increased dendrite build up on the zinc strips that were not insonified, whereas very little dendrite was observed on the zinc strips that had ultrasound applied to them via the resonant 1.4MHz piezo electric transducer, to which 50W of electrical power was supplied. The results were quantitatively analysed by extracting the dendrite height above the zinc electrode surface from the microscope images and all the information was summarised graphically in the form of videos, figure 3A is a screenshot of one of the videos. Several repeat measurements were performed and the transducer was also driven at different power levels.   |  | | --- | |  | | Figure 3: Screenshot of result summary video showing dendrite growth with and without applied ultrasound, on the left the microscope images are shown (snapshot at ~time=180secs) with the blue line indicating the original surface of the Zinc strip that faces the opposite electrode, the red line indicates the surface of the dendrite that grows after the current is applied; plots on the right show on the top the evolution of the mean dendrite height above the original Zinc electrode surface; and on the bottom the potential that is measured across the electrodes both when ultrasound is not applied (blue line) and when it is applied (red line) [1.4MHz, 40W]. |     These results are being written up more comprehensively and will be submitted for publication to a journal like electrochemical communications.  At this early stage it is very difficult to judge the overall impact. However, we have demonstrated that acoustic streaming can very effectively increase the ion transport and disrupt dendrite formation. Energetically, in the current form, it requires too much power to be useful. This is because the ultrasonic transducer indiscriminately dissipates energy over the whole vessel and is a very inefficient way to drive the streaming at the location where it is needed, i.e. the surface boundary layer. Nonetheless, we believe that if optimised the use of ultrasound to disrupt electrode degradation can become potentially very useful and this has been highlighted by the experimental results in this work. Therefore, future work should focus on delivering acoustic energy efficiently where it is needed and on controlling the localised ion transfer.  We are engaging academic and industrial partners in conversations and we hope that the newly-built rig and associated measurement data will help as catalyst to initiate new research into the efficient delivery of streaming into an area where it is needed. | | |
| **\*What activities have you undertaken to engage with research users, special interest groups and the general public to inform them about the research?**  A poster summarising the work has been presented at the IOP Physical Acoustics group Tutorial day on the 22nd of September 2023.  We are currently preparing a journal publication. | **\*Have any new research tools or methods been created or commissioned, if so, provide details:**  The above-mentioned rig that has been constructed is still operational and will be used for future project, i.e. we are currently using it for a student summer research project. | |
| **\*Have any new research datasets, databases and models making, or potential to make, significant difference to your research (or that of others), been created, if so, provide details: -**  Not yet, we hope this will happen in the future. | |
| **Conclusion:**  This research has enabled us to construct an experimental measurement rig that allows to study the effects of ultrasonic stimulation on electrochemical processes. We have collected some exciting results, which have been presented at the IOP PAG Tutorial day on 22nd September 2023 and which are being written up in form of a journal paper. We are also currently actively seeking future research funding for related work. | | |
| **Plans for follow-on activities/grants:**  We are writing up a publication (submission Q4 2023) and have already presented the outcomes at the IOP PAG Tutorial day (22nd September 2023). The rig that was constructed is being used for a summer student research project and will hopefully be used in a final year research project in the coming academic year. Dr Zhang is preparing an application for follow-on research funding which we hope to submit in early 2024. | | |
| **Weblink:** (to the outcome of the project, the Open Access repository for the data[[1]](#footnote-1), or press releases):  Not yet available, TBC | | |
| **List of publications:** in peer reviewed or non-peer reviewed literature. If no publications are available, what are the plans to publish? Please follow UKRI guidelines for Open Access [**https://www.ukri.org/manage-your-award/publishing-your-research-findings/**](https://www.ukri.org/manage-your-award/publishing-your-research-findings/)  Not yet available, TBC | | |

1. As a UKRI award holder you must follow their research data policies- <https://www.ukri.org/manage-your-award/publishing-your-research-findings/making-your-research-data-open> [↑](#footnote-ref-1)