



Durable Materials for a Sustainable Society

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Introduction

The global transition to renewable energy and sustainable technologies is driving the need for innovative advancements in materials science and manufacturing processes. Metal additive manufacturing (AM), commonly referred to as 3D metal printing, offers transformative potential across various industries by enabling the creation of novel metal alloys with enhanced features, bespoke designs, and rapid repair capabilities. This technology not only facilitates the development of highly customised solutions but also promotes sustainability by minimising material wastage and extending the lifespan of conventionally manufactured components. As such, AM holds promise for addressing critical challenges in industries such as aerospace, energy, and automotive, where material efficiency and performance are paramount.

Despite its advantages, the widespread adoption of additively manufactured metals is limited by uncertainties regarding their long-term durability, particularly their resistance to degradation through corrosion. Corrosion resistance is a critical property for materials used in applications where environmental exposure significantly affects functionality, safety, and efficiency. For instance, water pipes must be resistant to corrosion to prevent leaks, contamination, and costly replacements. Similarly, materials used in food packaging, such as metal foils, require high corrosion resistance to maintain integrity and avoid contamination during prolonged storage. In structural applications, such as bridges and offshore platforms, corrosion can compromise load-bearing capacity and lead to catastrophic failures if not adequately managed. Understanding the corrosion behaviour of materials is thus essential to ensure their suitability for specific applications, reduce maintenance costs, and enhance the lifespan of critical infrastructure.

This project seeks to address these limitations by evaluating the corrosion behaviour of additively manufactured (AM) metals in comparison with their conventionally manufactured counterparts. The assessment will employ techniques such as Potentiodynamic Polarisation and Electrochemical Impedance Spectroscopy (EIS) to provide a comprehensive understanding of corrosion resistance. Integrated machine learning models will further analyse and predict the corrosive properties of AM metals produced using Laser Powder Bed Fusion (LPBF), enabling a data-driven approach to optimise material performance.

The findings will offer valuable insights into the industrial suitability of AM metals, highlighting their potential for wider adoption in sustainable applications. By combining advanced electrochemical analysis with machine learning, the project aims to advance the understanding of AM metals' durability, facilitating their application in industries that prioritise material efficiency and longevity. Furthermore, the project will provide opportunities to develop critical skills in experimental design, corrosion testing, and data-driven material

analysis, underscoring the importance of interdisciplinary approaches in advancing sustainable technologies.

Conducted Research

The primary aim of the research was to evaluate the corrosion resistance of additively manufactured (AM) metals and compare their behaviour to conventionally manufactured counterparts. This involved conducting electrochemical studies using Electrochemical Impedance Spectroscopy (EIS) and Potentiodynamic Polarization to assess material degradation under varying thermal conditions. The focus was on AM aluminium components fabricated using Laser Powder Bed Fusion (LPBF) and their conventionally manufactured equivalents.

EIS analyses provided critical insights into corrosion resistance through impedance and phase angle data, while varying temperatures (25°C to 70°C) were applied to simulate industrial conditions. The collected data enabled the identification of distinctive corrosion behaviours exhibited by AM and conventional aluminium materials, particularly in terms of thermal stability and protective layer integrity. In parallel, a literature review was conducted to contextualise findings within existing research and identify gaps that the study could address. This hybrid approach of experimental and theoretical analysis aimed to generate a comprehensive understanding of AM materials' corrosion performance.

The integration of machine learning was another key component of the research. Electrochemical data obtained from EIS experiments were used to train predictive models that could analyse and forecast the corrosion behaviours of AM metals. By developing a database of electrochemical data and AM material properties, the project laid the groundwork for future optimisation of AM processes for improved durability and industrial applications.

Challenges and Solutions

One of the primary challenges faced during the research was the clash with my KAIST internship in South Korea, which overlapped with the third week of the project. This constraint necessitated a modification of the original research plan to ensure the continuity and quality of the work. The solution involved adopting a hybrid research approach that combined experimental data collection, literature analysis, and the integration of machine learning models.

While EIS experiments were conducted in the early phases of the project, the subsequent weeks focused on synthesising findings from literature and leveraging machine learning to enhance data interpretation. This approach not only allowed the research to progress seamlessly but also diversified its scope, incorporating elements of theoretical analysis and computational

modelling. The hybrid strategy enabled the project to maintain its objectives while addressing logistical constraints, ultimately contributing to a more robust and versatile research output.

Importance and Impact of the Research

The research conducted on the corrosion resistance of additively manufactured (AM) metals holds significant importance in advancing materials science and engineering, particularly in the context of energy and materials sustainability. Additive manufacturing, particularly using techniques like Laser Powder Bed Fusion (LPBF), has revolutionised the production of metals, offering bespoke designs, enhanced properties, and reduced material wastage. However, uncertainties regarding the long-term durability of these materials, especially their resistance to corrosion, pose a barrier to their widespread adoption in critical industries. By providing detailed insights into the corrosion behaviour of AM metals compared to conventionally manufactured counterparts, this research addresses a crucial gap in knowledge and builds confidence in the industrial viability of AM materials, particularly within the energy and materials sectors—areas that align closely with chemical engineering principles.

The potential applications and long-term benefits of these findings are impactful across the energy industry, where corrosion resistance directly affects the reliability and efficiency of critical systems. For instance, AM metals with enhanced corrosion resistance could be used in renewable energy infrastructure, such as wind turbine nacelle frames, solar panel supports, or hydrogen storage tanks. Improved durability reduces material degradation, extending operational lifespans and contributing to the efficiency of renewable energy systems. Similarly, in energy-intensive chemical processing plants, corrosion-resistant AM components can be employed in heat exchangers, reactors, and pipelines, where harsh operating conditions often lead to significant material deterioration. This reduces maintenance costs, minimises downtime, and ensures safer, more sustainable operations.

In the field of materials sustainability, this research addresses the demand for lightweight, durable materials that reduce environmental impact. For example, in electric vehicles (EVs), lightweight, corrosion-resistant AM aluminium alloys could be used for battery enclosures and structural components, improving energy



efficiency and vehicle range. In the medical field, AM metals with superior durability can be employed in implants and surgical instruments, offering long-lasting solutions that reduce waste and improve patient safety. Furthermore, in water management and infrastructure, AM

materials with enhanced corrosion resistance could extend the lifespan of pipelines, valves, and fittings, reducing resource consumption and minimising environmental degradation.

This research also highlights the innovative potential of combining experimental corrosion analysis with machine learning. Predictive models derived from electrochemical data can enable the optimisation of AM alloys for specific environments, such as saline or high-temperature conditions, facilitating the development of customised solutions tailored to industrial needs. Advanced surface treatments or coatings, informed by this research, could further enhance the durability of AM metals, ensuring their suitability for critical applications in the energy and chemical engineering sectors.

The contribution of this research to sustainability and innovation is profound. By reducing material wastage through precise AM processes and extending the lifespan of components, the findings align with global sustainability goals and support circular economy principles. The integration of AM metals into energy and chemical engineering applications fosters efficiency, safety, and environmental responsibility, directly contributing to the decarbonisation of industries and the achievement of Net Zero targets.

In bridging the fields of energy, materials science, and chemical engineering, this research underscores the importance of interdisciplinary approaches to addressing global challenges. It not only enhances the understanding of AM materials but also fosters transformative innovations that provide sustainable, durable, and efficient solutions for industries critical to the future of energy and materials sustainability.

Dissemination of Research

The dissemination of my research has been an integral part of the project, enabling me to share findings, receive valuable feedback, and explore interdisciplinary connections. I actively presented my research to peers within my chemical engineering major, including not only my cohort but also senior students, fostering discussions about the methodologies, technologies, and sustainable applications of the findings. These presentations provided an excellent platform to highlight the significance of additive manufacturing (AM) metals and the advanced analytical techniques, such as Electrochemical Impedance Spectroscopy (EIS), employed in assessing their corrosion resistance. By discussing the broader applications of the research in sustainability and industry, I sparked insightful conversations about its potential impact on energy and materials sectors.

A key milestone in sharing my research was the creation of a research poster. This process was highly collaborative, incorporating feedback from my supervisor and PhD students specialising in corrosion within the same department. Their insights, grounded in our common research area, significantly enhanced the clarity and depth of the poster, ensuring that it effectively

communicated the objectives, methodologies, and outcomes of the study. Additionally, my peers reviewed the initial designs, offering constructive suggestions to refine the visual and textual presentation. The final poster became a powerful tool for summarising and disseminating my work in a concise and professional manner.

To further promote my research, I leveraged digital platforms and outreach initiatives. I shared my findings and experiences through posts on LinkedIn, where I received engagement and feedback from individuals across various disciplines, including business and biotechnology. My testimonials, one of which was featured on the official website of the University of Leeds, amplified the visibility of the project and highlighted the interdisciplinary potential of the research. The feedback from these diverse audiences underscored the relevance of the study beyond traditional engineering fields, as professionals expressed interest in exploring cross-disciplinary applications and innovative solutions to industry challenges.

The feedback I received played a crucial role in shaping my perspective on the broader impact of my work. Discussions with individuals from different fields highlighted potential applications of corrosion-resistant AM metals in areas such as biotechnology, product design, and even business innovation. These interactions encouraged me to explore research fields and career paths that extend beyond the immediate scope of chemical engineering. I began to investigate opportunities to bridge gaps between disciplines, recognising the value of collaborative efforts in driving innovation.

Overall, the dissemination of my research not only broadened its reach but also enriched my understanding of its interdisciplinary significance. Through presentations, collaborative poster design, and outreach, I gained deeper insights into the potential of my work and identified new areas for future exploration. This experience has not only enhanced my communication and networking skills but has also inspired me to seek opportunities that extend the boundaries of my major, furthering my academic and professional growth.

Personal Impact of Conducting Research

Conducting this research has significantly shaped my perspective on chemical engineering, highlighting its crucial role in advancing sustainability through interdisciplinary innovation. The project deepened my appreciation for the intersection of materials science, energy, and sustainability, showcasing how chemical engineering can drive impactful solutions in these areas.

I acquired technical skills in Electrochemical Impedance Spectroscopy (EIS), Potentiodynamic Polarisation, and machine learning integration, enhancing my ability to analyse complex data and evaluate material performance. My communication skills improved through presenting

findings to diverse audiences, collaborating with peers and mentors, and creating a research poster informed by feedback.

The experience bolstered my **confidence, adaptability, and problem-solving abilities**, especially when navigating challenges such as balancing this project with my KAIST internship. This required innovative approaches, including hybrid research methods. Feedback from interdisciplinary audiences broadened my outlook, inspiring me to explore connections beyond chemical engineering and consider new research and career opportunities.

Overall, the project has been transformative, strengthening my skills and reinforcing my commitment to applying chemical engineering to sustainability-focused innovations.

Leadership Skills Gained

The research project provided a valuable opportunity to hone my leadership skills, particularly in decision-making, judgment, and taking responsibility for the direction and quality of experimental work. As the primary researcher, I was responsible for designing and executing experiments, making critical decisions regarding methodologies, and adapting the research plan to address challenges. For example, balancing the timeline of this project with my KAIST internship required **strategic prioritisation** and adjustments, such as integrating hybrid approaches of experimental analysis, literature review, and machine learning. These decisions ensured the project's continuity and success despite logistical constraints.

Throughout the research, I consistently demonstrated sound judgment in experimental design and data interpretation. By critically assessing results from Electrochemical Impedance Spectroscopy (EIS) and Potentiodynamic Polarization techniques, I refined the experimental protocols to enhance the accuracy and reliability of the findings. This decision-making process was guided by an ability to evaluate trade-offs and anticipate potential outcomes, which are crucial leadership skills in scientific research.

The project also reinforced leadership skills I had previously developed, including collaboration and mentorship. I engaged with peers, supervisors, and PhD students, incorporating their feedback into the research poster and experimental design. This process required **effective communication, openness to constructive criticism**, and the ability to synthesise diverse perspectives to improve the overall quality of the work. These interactions strengthened my collaborative leadership capabilities, further refining my ability to manage input from various stakeholders while maintaining the project's focus.

These leadership experiences have had a direct impact on the progress and quality of the research. My ability to make well-informed decisions ensured the experiments produced meaningful results, while my collaborative approach enhanced the clarity and dissemination of

the research findings. Overall, this project has been instrumental in developing my leadership skills, which will serve as a strong foundation for future research and professional endeavours.

Future Career and Educational Plans

The research experience has been instrumental in shaping and refining my career aspirations, particularly in the intersection of materials science and sustainability. My interest in materials stems from high school, where I was inspired by investigating the material properties of badminton rackets and how they influence performance. The precision and unique characteristics required for manufacturing badminton rackets align closely with my broader passion for sustainable materials—areas that demand innovation, high performance, and environmental responsibility. This project has highlighted the infinite cross-disciplinary connections within materials science, from energy applications to sustainability goals embedded within Environmental, Social, and Governance (ESG) frameworks.

This realisation has solidified my ambition to pursue a master's degree in **advanced chemical engineering** rather than focusing too narrowly on a specific niche, such as material science, at this stage. By opting for a broader curriculum, I aim to explore the overlapping areas of materials and energy, gaining a holistic understanding of both fields before committing to a specialisation. This approach will allow me to discover where my strengths and passions lie while building a versatile foundation for future innovation.

I am inclined to continue researching durable materials and investigating topics related to additive manufacturing, corrosion resistance, and sustainability. However, I also recognise the value of diversifying my experiences during the remaining years of my bachelor's degree. By exploring various topics and applications, I can further enrich my understanding of chemical engineering and its interdisciplinary potential.

In the long term, this research has reinforced my commitment to a career in sustainable materials and energy. Whether it involves the development of high-performance materials for sports equipment like badminton rackets or durable components for renewable energy systems, I am driven by the opportunity to make impactful contributions. This project has given me the confidence and curiosity to explore the broader landscape of materials and energy, ensuring that my career path is both informed and adaptable to the evolving needs of society.

Conclusion

The research period has been an enriching journey, equipping me with valuable professional skills, academic growth, and a deeper appreciation for the impact of research. Through this experience, I developed expertise in corrosion resistance analysis, integrating advanced techniques like Electrochemical Impedance Spectroscopy (EIS) and machine learning. Working on a hybrid research model while in South Korea highlighted the importance of consistent communication with my supervisor and team members, ensuring progress and alignment despite logistical challenges. This taught me the significance of adaptability and collaboration in professional research settings.

Reflecting on my academic growth, I now realise the practical value of what I have learned in my material science modules. This experience allowed me to apply theoretical concepts to real-world problems, bridging the gap between classroom learning and industrial application. Previously, I would attempt to relate textbook knowledge to real-world phenomena, but this research has reversed that process; I now analyse experimental results and connect them back to foundational theories. This approach has made my learning more meaningful and memorable, strengthening my understanding of material science and its applications.

Professionally, collaborating with my supervisor and PhD students provided me with an entirely new perspective on teamwork and efficiency. Discussions were focused and results-driven, with a shared understanding of technical language and departmental tools, which significantly enhanced the quality of our work. This experience has inspired me to apply similar strategies to my academic design projects, fostering better collaboration and outcomes within my teams.

The research reaffirmed my belief in the boundless potential of durable materials, particularly metals, for applications in machinery, industrial plants, and beyond. Innovations in this area can lead to materials that are lighter, cheaper, and more robust, with higher melting points and improved sustainability. These advancements align with the United Nations Sustainable Development Goals (UNSDG), such as affordable and clean energy (Goal 7), decent work and economic growth (Goal 8), industry innovation and infrastructure (Goal 9), sustainable cities and communities (Goal 11), responsible consumption and production (Goal 12), and climate action (Goal 13). I see this research direction as a cornerstone for addressing global challenges and creating lasting positive impacts on society and the environment.

In summary, this research experience has been invaluable for my academic and professional development, solidifying my passion for material science and its real-world applications. It has provided me with the tools and insights to contribute meaningfully to sustainable innovations, and I am eager to continue exploring this field to drive solutions that address pressing global issues.