MET-TRICKS
(Problem Statement)

1. Problem Statement: Improving Additive Manufacturing for Aluminum Alloys

- Challenge: Challenges in additive manufacturing (AM) of aluminum alloys include porosity, cracking, and limited selection of alloys. How can these challenges be addressed to improve the adoption of AM for aerospace and automotive applications?

- Study: Porosity and hot cracking are among the most prevalent defects in the AM process.

- Solution: Possible techniques include optimization of laser parameters, modification of alloys, or post-processing (e.g., heat treatment or HIP).

- Outcome: Suggest a roadmap to attain increased density, enhanced mechanical strength, and superior surface finish of AM-processed aluminum alloys.

2. Problem Statement: Recovering Lithium from Spent Batteries

- Problem: With the rapid growth of electric vehicles, portable electronics, and renewable energy storage systems, the demand for lithium has increased sharply. A large number of spent lithium-ion batteries are being generated, and improper disposal poses serious environmental and resource sustainability concerns. Although lithium is a critical and valuable metal, its recovery from end-of-life batteries remains challenging due to complex battery chemistries, safety issues, high processing costs, and environmental impacts of existing recycling routes.

- Explore Techniques: Assess pyrometallurgical, hydrometallurgical, and direct recycling/bio-hydrometallurgical methods for lithium recovery from spent lithium-ion batteries.

- Optimize Processes: Improve lithium recovery efficiency while reducing energy consumption, reagent usage, greenhouse gas emissions, and secondary waste generation.

- Outcome: Develop a sustainable, safe, and economically viable framework for efficient lithium recovery from spent batteries, supporting circular economy practices and reducing dependence on primary lithium resources.

3. Problem Statement: Mitigating Hydrogen Embrittlement in High-Strength Steels

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- Challenge: Hydrogen embrittlement leads to premature failure in high-strength steels, especially in critical applications like pipelines and bridges. What measures can minimize this risk?
- Investigate Mechanisms: Investigate how hydrogen interacts with the microstructure of the steel.
- Control Strategies: Research possibilities in changing the microstructure, alloy design including Cr and Mo additions, and coating.
- Outcome: Provide an integrative view towards designing hydrogen-embrittlement-resistant steels.

4. Problem Statement: Development of Alternative Alloys for Bioprosthetic Applications

- Problem: Titanium and its alloys, Stainless steel are widely used in bioprosthetic and biomedical implant applications due to their excellent biocompatibility, corrosion resistance, and mechanical strength. However, their high cost, stress shielding effects caused by elastic modulus mismatch with bone, limited wear resistance in certain applications, and challenges in processing and fabrication have motivated the search for alternative alloy systems. There is a growing need to develop cost-effective, mechanically compatible, and biologically safe alternative alloys that can match or surpass the performance of titanium alloys in bioprosthetic applications.
- Explore Materials and Techniques: Investigate alternative alloy systems such as magnesium-based, cobalt-free stainless steels, zirconium-based, tantalum-based, and high-entropy alloys, along with suitable surface modification and alloying strategies to enhance biocompatibility, corrosion resistance, and mechanical performance.
- Optimize Properties: Tailor alloy composition and processing routes to achieve an elastic modulus closer to that of natural bone, adequate strength and fatigue resistance, improved wear and corrosion behavior, and long-term biological safety.
- Outcome: Develop a sustainable, cost-effective, and clinically viable alternative alloy framework for bioprosthetic applications that reduces reliance on titanium alloys while improving patient outcomes and implant longevity.

5. Problem Statement: Development of Alternative Materials to Stainless Steel for Indian Railways Applications

- Problem: Stainless steel is extensively used in the body structures of Indian Railways due to its strength, corrosion resistance, and durability. However, the high material cost, increased vehicle weight, energy-intensive production, and challenges in large-scale fabrication and repair limit its long-term economic and operational efficiency. Additionally, heavier coach bodies contribute to higher energy consumption and reduced speed potential. There is a growing need to identify and develop alternative materials that can offer comparable or superior mechanical performance, corrosion resistance, safety, and service life at reduced cost and weight.

- Explore Materials and Technologies: Evaluate alternative materials such as advanced high-strength low-alloy (HSLA) steels, aluminum alloys, fiber-reinforced polymer composites, and hybrid metal–composite structures suitable for railway coach body applications.

- Optimize Performance: Optimize material selection and processing routes to achieve weight reduction, cost efficiency, enhanced corrosion and fatigue resistance, improved crashworthiness, and ease of fabrication and maintenance under Indian operating conditions.

- Outcome: Develop a sustainable, lightweight, and cost-effective material framework for railway coach bodies that reduces dependence on stainless steel while improving energy efficiency, safety, and lifecycle performance of Indian Railways rolling stock.

6. Problem Statement: Enhancing Corrosion Resistance in Magnesium Alloys

- Challenge: Magnesium alloys, despite being lightweight, are highly susceptible to corrosion, limiting their usage in automotive and aerospace applications. How can their corrosion resistance be improved?

- Analyze Causes: Identify mechanisms of corrosion in magnesium alloys under specific environments.

- Suggest Solutions: Investigate alloying elements, such as Al, Zn, or rare earths; surface treatments, like anodizing or coatings; and inhibitor addition.

- Result: Create a magnesium alloy that offers resistance to corrosion with improved service life.