Curtin University

CURTIN CORROSION CENTRE

Cooperative Research Centres Projects (CRC-P) Grants

FUNCTIONALLY-GRADED MATERIALS FOR EXTREME ENVIRONMENTS MADE BY ADDITIVE MANUFACTURING

Make tomorrow better.

The business case

The Oil and Gas (O&G) and Mining industries will benefit from a new generation of materials with site-specific properties tailored to meet the challenges associated with operations in extreme environments (e.g., high pressure and temperature, erosion and corrosion, etc.). Today, however, no readily available manufacturing process could provide components with functionally-graded properties to meet site-specific properties.

A modified Direct Energy Deposition (DED) method can revolutionize Additive Manufacturing (AM) of complex parts and components with site-specific properties not achievable by conventional and even other AM technologies.

Industry-led research

The project plans to adopt an industry-driven research approach. Participating companies and Curtin University will form an Industry Advisory Board (IAB), which will oversee the project and guide the research methodology.

The industry partners will provide a guideline on component requirements, i.e., the distribution of target properties at different sites on selected components.

Benefits

The project will deliver a new industry-focused AM process based on DED to generate compositionally-graded components (i.e., a part that contains different alloys at different locations) to meet site-specific properties for extreme O&G and Mining.

The new method will also enable quick repairs of damaged components, a concept already proven in the aerospace industry.

Target Properties: the IAB will define the target properties and select the components to be designed. We propose two combinations:

(i) High-strength core – Hydrogen and corrosion resistant outer layer (O&G and Mining).
(ii) High strength core – Wear-resistant outer layer (O&G and Mining).

How

Curtin University will design and commission a state-of-the-art DED unit in collaboration with a world-leader AM equipment manufacturer. The new AM Hub at Curtin University's John de Laeter Centre will house the equipment.

The DED process will be tailored based on fundamental physical metallurgy principles and AM and thermal processing practices.

Who

Potential industry lead and partner:

- Lead industry partner
- Partner industry A
- Partner industry B

Potential Small-Medium-Enterprise (SME) partner:

- SME 1
- SME 2

Curtin research team:

A. **Research Director:** Professor Mariano Iannuzzi, Curtin Corrosion Centre Director with 15 years of industrial and academic experience.
B. **Team member:** Dr Zakaria Quadir, Characterization and Physical Metallurgy expert.
C. **Team member:** Dr Mobin Salasi, materials and corrosion expert.
D. **Team member:** Dr Garry Leadbeater, Industry expertise in mechanical engineering and metallurgical design.

Participation fees

SME Contribution $30K for 3 years | $10K/year
Industry Cash Contribution $630K for 3 years | $70K/year per company
Curtin Contribution $450K for 3 years | $150K/year
In Kind Contribution Industry: $280K in total | Curtin: $200K in total

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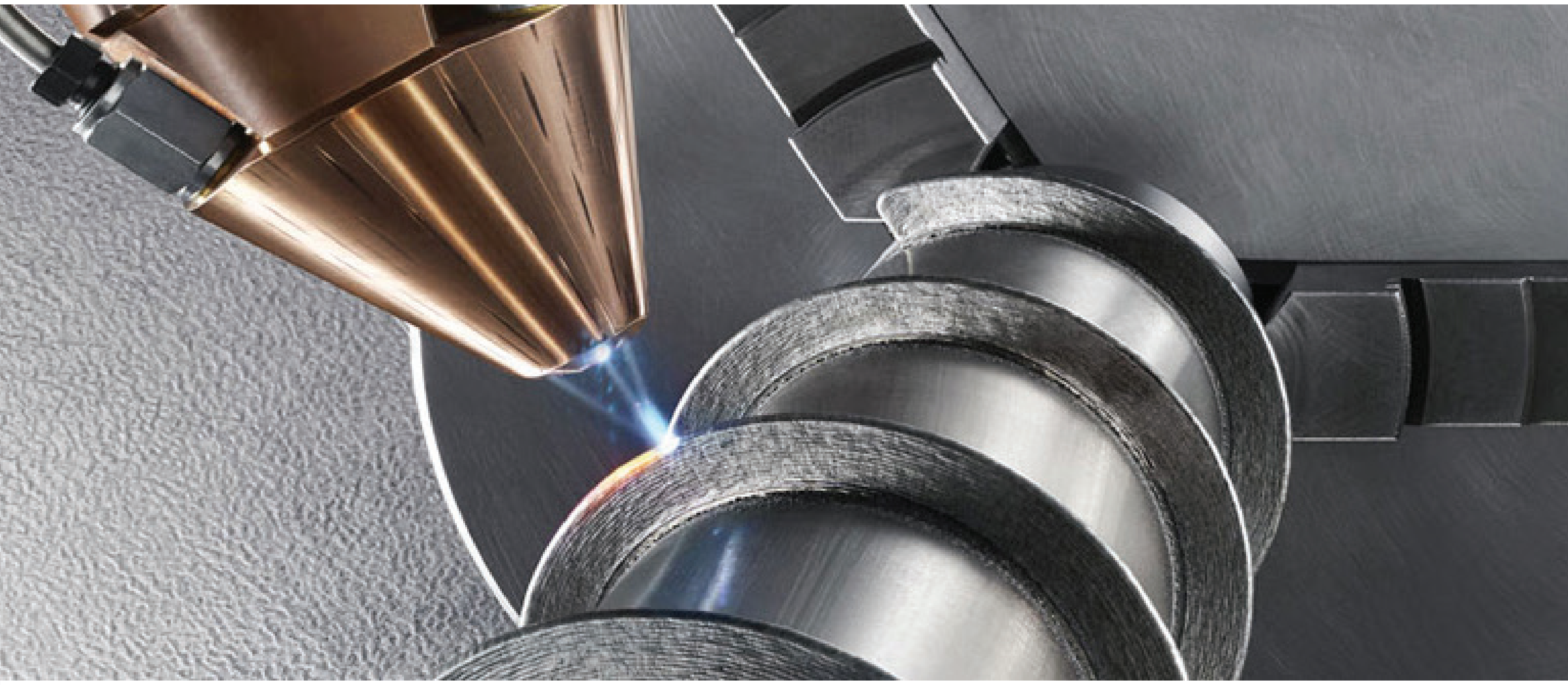
Department of Industry, Innovation, and Science Contribution up to $1065K for 3 years | $355K/year

=

$2655K



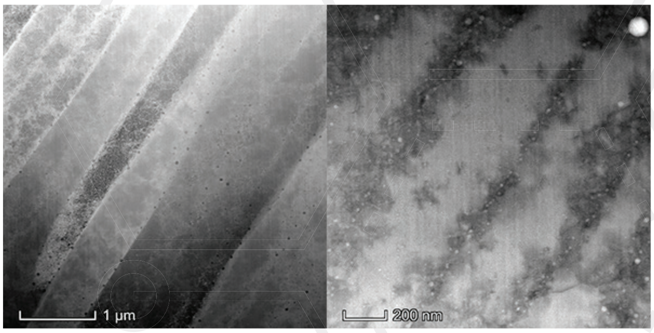
The science and the methods

The O&G and Mining industries require alloys for the safe and profitable exploitation of unconventional natural resources. In the O&G industry, for example, materials must endure extreme environments including, e.g., external artic temperatures, high internal pressures and temperatures, as well as corrosive conditions that result in the formation of atomic hydrogen. Similarly, mining equipment is exposed to some of the most corrosive environments. In both cases, limited direct surveillance and monitoring systems in remote facilities exacerbate the problem.

There is consensus in that alloys combining high strength, toughness, fatigue life, wear, corrosion and hydrogen embrittlement resistance are paramount for the development of the next generation of equipment for extreme O&G production and mining. However, conventional alloy manufacturing methods produce materials that cannot meet all requirements simultaneously. Moreover, conventional metal manufacturing techniques are incapable of delivering the required performance when location-specific functionality is required within the same engineering component. A chief reason for this is the lack of control in conventional methods in placing different materials at different locations within the same integrated part, except for simple surface modifications such as cladding and functional coatings (e.g., WC and diamond-like carbon deposition).

Recent developments have shown that the combination of seemingly contradictory properties, such as simultaneous improvements in strength and hydrogen resistance, is achievable by innovative AM techniques that allow the development of functionally-graded components with varying mechanical, thermal, optical, magnetic, wear, etc. properties. **This project will focus on the exploration of AM techniques to produce functionally-graded components.**

The DED operating principle is simple. It is a 3D bottom-up manufacturing process with different metals/alloys. DED builds the desired component with a location-specific alloy composition as demanded by a given engineering application. An advanced DED machine consists of up to 4 nozzles mounted on a multi-axis arm. The nozzles can flexibly move and deliver different metal powders or alloy rods that can be deposited by melting with a laser or electron beam.



Transmission Electron Microscope Image of the additively manufactured 316L stainless steel sample.

DED is not restricted to metals and alloys. Indeed, DED can also incorporate polymers and ceramics. A simplified schematic of the process is shown in Figure 1, illustrating a component with different materials throughout its height and thickness.

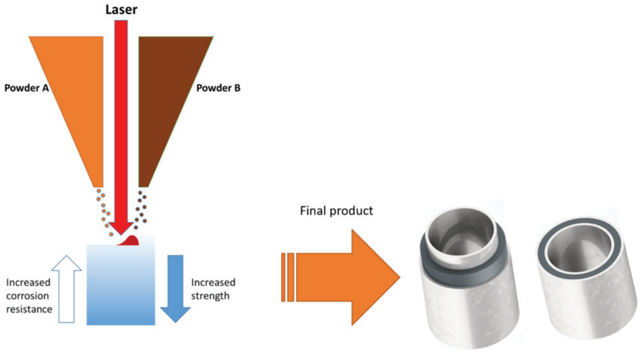


Figure 1: A schematic of the DED process showing different material getting printed under laser and two example components having material gradients along with the thickness and length.

Quick repairs: DED can be used to upgrade a monolithic alloy part by, e.g., placing different layers at different locations on a metal component, thereby adding new materials. DED can also be used to quickly repair damaged components by depositing materials at the damaged/corroded/wear/tear sites. DED repair potential has been already proven on, e.g., aircraft component restoration.

Science-backed outcomes

The Curtin research team will conduct an engineering design detailing the external and internal structures. Then, the team will embark on the selection of the materials and the optimization of the AM parameters to produce compositional gradients at targeted locations of the component.

After materials selection and AM optimization, the components will be manufactured and post-processed (e.g., heat-treated) before conducting detailed testing in the context of the application condition, as defined by the IAB. The characterization will include state-of-the-art microscopy, mechanical and environmentally assisted corrosion testing, as well as hydrogen transport properties and wear resistance analysis. Lastly, the SMEs will support the component design stage, undertake a proof of concept evaluation, and provide feedback on the readiness for the real-world applications.