Macro-scale Modeling of Nickel Dispersion Plating Processes

EU MOZART - ELSYCA 2025

The MOZART project has received funding from the European Union's Horizon Europe research and innovation program under the Grant Agreement No. 101058450.

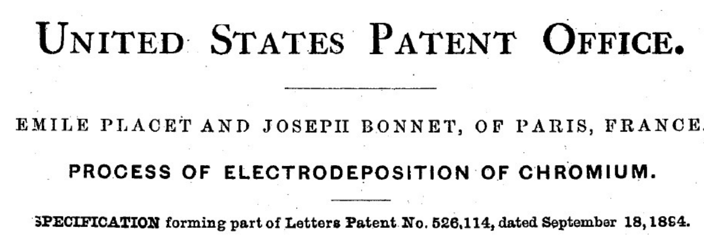
What you need to know

- The Mozart project seeks a suitable replacement for hard chrome by enriching a nickel coating with hard nano-particles
- The real-world demonstrator case highlights the difficulty in achieving uniform particle distribution (and hardness) across the full part surface
- Controlling and predicting particle distribution is critical to ensure the right particle content in key areas
- Developed an electrochemical modelling technology to simulate alternatives to hard chrome

Hard chrome

Applications

- Hard chrome has been widely used for nearly 100 years due to its excellent wear, hardness, and corrosion resistance
- Traditionally electroplated chromium uses Cr(VI) – a toxic, carcinogenic, and mutagenic compound
    - Increasing regulatory pressure to phase out due to health and environmental risks
- Alternative chromium coating technologies exist, but most still rely on electrolytic processes → A true drop-in replacement is needed:
    - Trivalent hard chrome
    - Particle-reinforced dispersion coatings (metal matrix with embedded particles)



UNITED STATES PATENT OFFICE.

EMILE PLACET AND JOSEPH BONNET, OF PARIS, FRANCE.

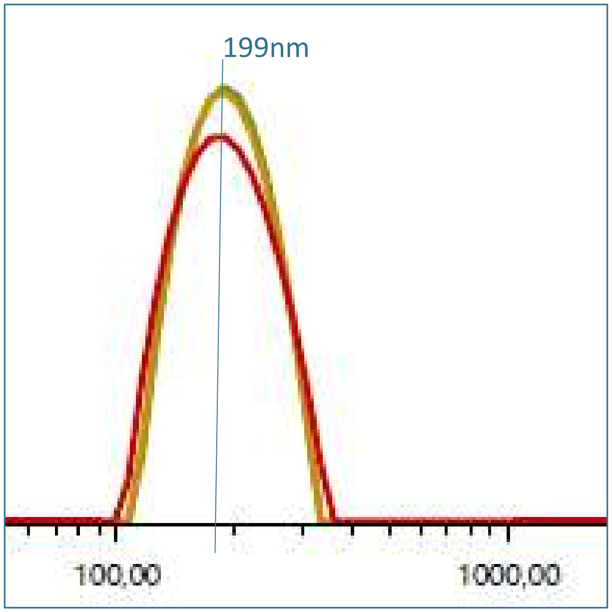
PROCESS OF ELECTRODEPOSITION OF CHROMIUM.

SPECIFICATION forming part of Letters Patent No. 526,114, dated September 18, 1894.

MOZART project

Scope

- Investigate nickel matrix nano-composite electroplated process, i.e. nickel coating enriched with hard nano-particles
- Different nano-particle are being investigated, here we present the silicone-carbide case
- Nano-particles size is targeted at 200 nm, with layer incorporation up to 8%
- Preliminary results show hardness values up to 850 HV, within the hard chrome range (750-1050 HV)



Particle distribution [nm]

Lab characterization

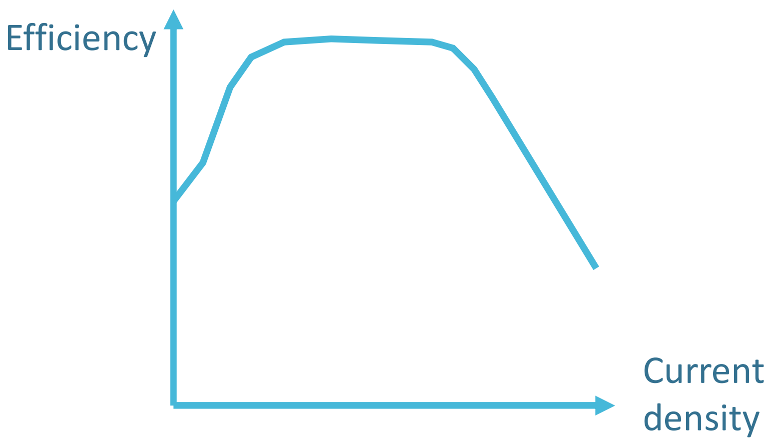
Introduction

Polarization

- Polarization curves represent the correlation between potential difference at the part/bath interface vs resulting current density
- The potential difference across the interface is a result of all resistances along each current path
- The resulting current density defines the deposit characteristics, and combined with plating time, the layer thickness

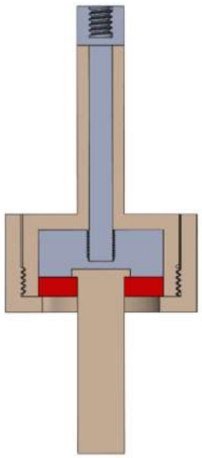
Plating efficiency

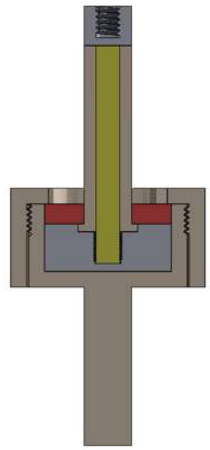
- Plating efficiency represent the proportion of current that is effectively used in the plating process
- Side-reactions, such as hydrogen evolution or additive reduction will reduce the plating process efficiency



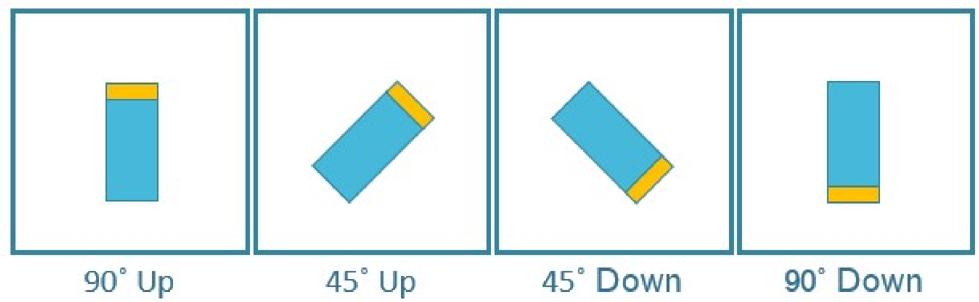
Lab characterization

Mozart experimental setup





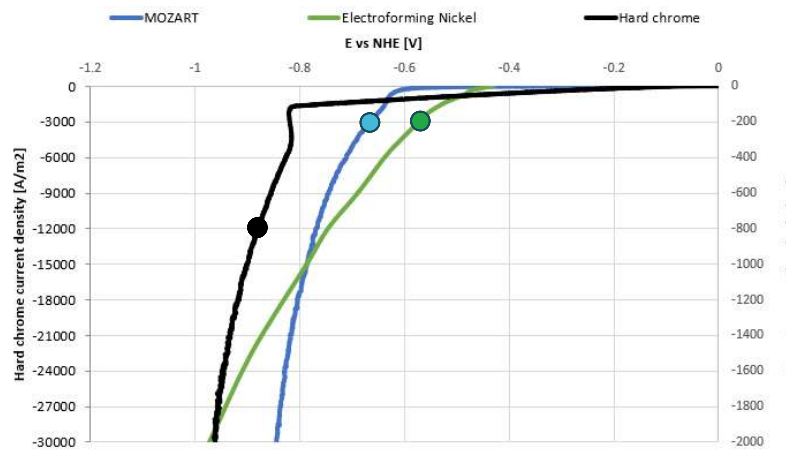
- Custom Rotating Ring Electrode was fabricated
  - Controlled hydrodynamics
  - Convertible holder (upwards or downwards facing)
  - Replaceable coupon samples
  - Compatible with standard RDE rotor

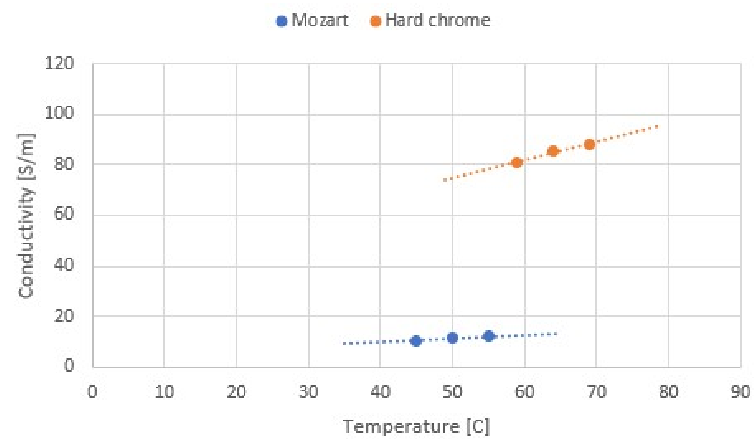


Lab characterization

Polarization results

- Conductivity and polarization slope contribute to define throwing power, i.e. the edge effects magnitude
- Polarization slope
  - Mozart comparable to other nickel baths
  - Mozart less steep than hard chrome → Lower edge effects than hard chrome
- Conductivity
  - Similar to other nickel baths (overlapping Mozart = not shown)
  - Mozart conductivity 7x smaller than hard chrome→ Higher edge effects than hard chrome
- Modelling is required to properly account all variables

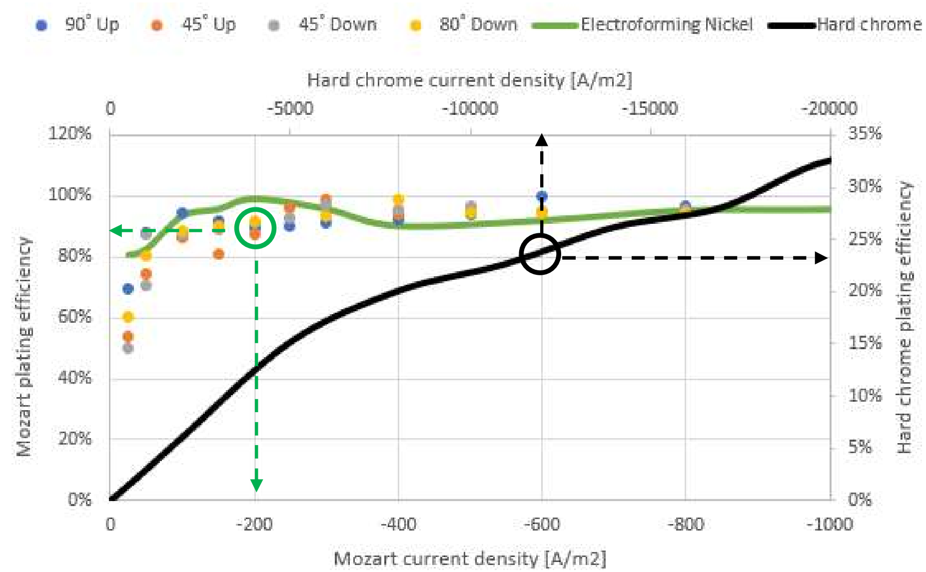




Lab characterization

Plating efficiency results

- Mozart bath has a much higher efficiency than hard chrome (12 000 A/m^2)
- Hard chrome plating efficiency growing with current density magnifies edge effects
- Mozart plating efficiency consistent with other nickel baths
  - ≈100% and decreasing at lower current densities
  - Operating at ≈200 A/m2, efficiency grows less than for hard chrome
- **Downwards facing surfaces show lower efficiency**

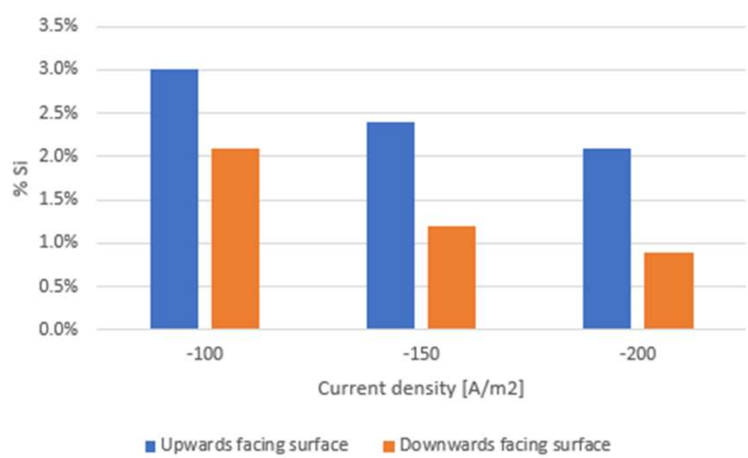


Lab characterization

SiC content

Particle content

- Particle content decreases between upwards and downwards surface orientation
- Particle incorporation decreases with increasing current density

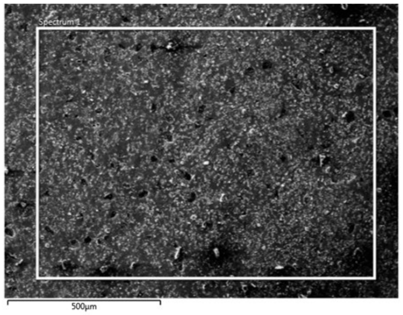


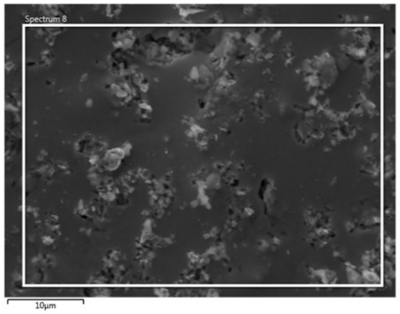
Morphology

100x

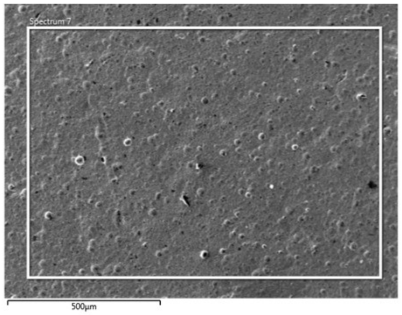
2500x

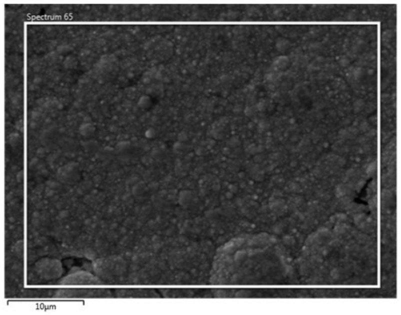
Low current density





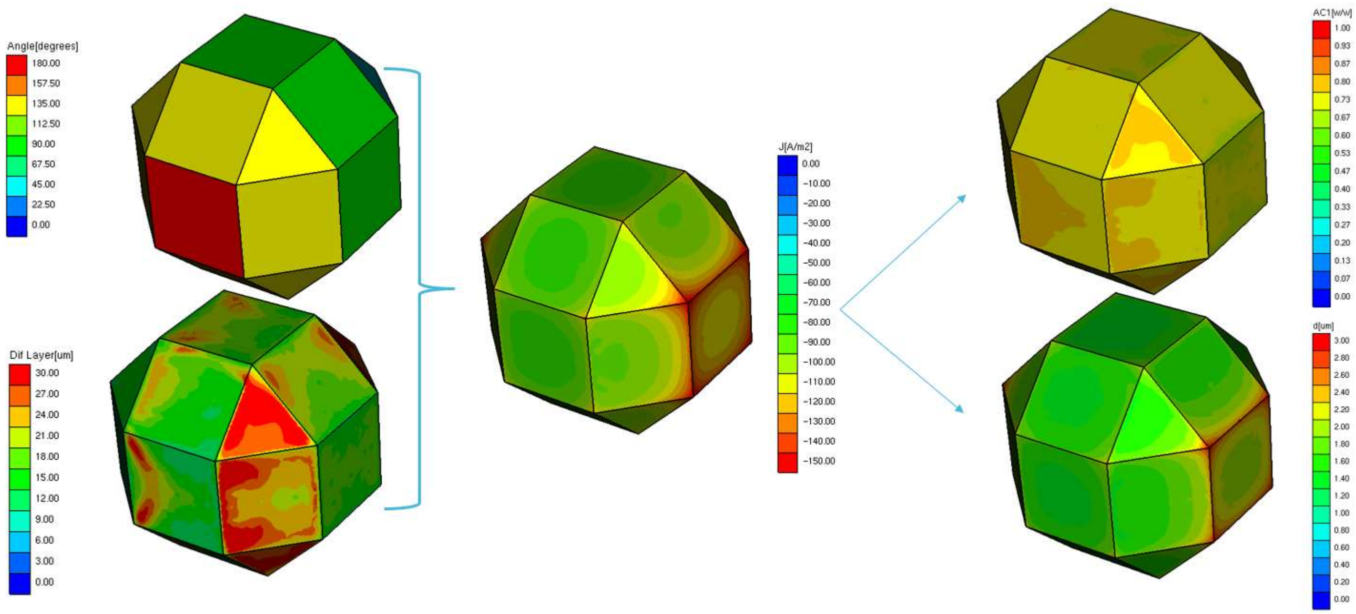
High current density





Modelling dispersion coatings

Approach



Surface orientation identification

Local agitation conditions

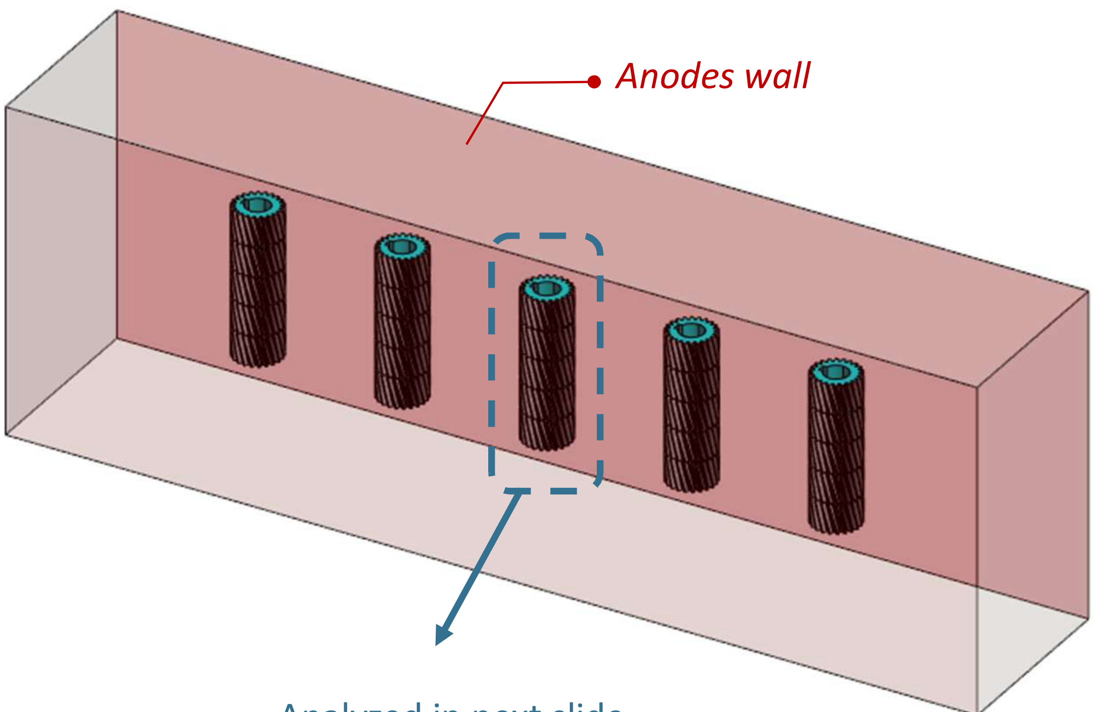
Current density distribution

Particle content

Layer thickness

Modelling dispersion coatings

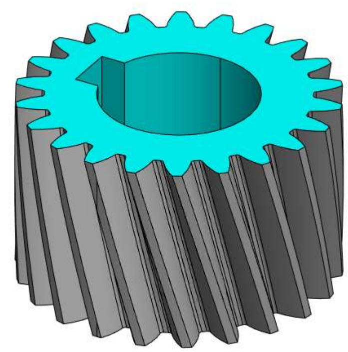
No Tooling configuration

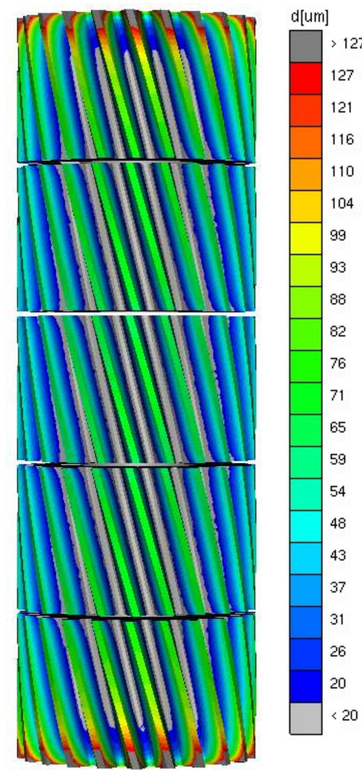


Analyzed in next slide

A type surface
(full specs area)

C type surface
(no specs area)

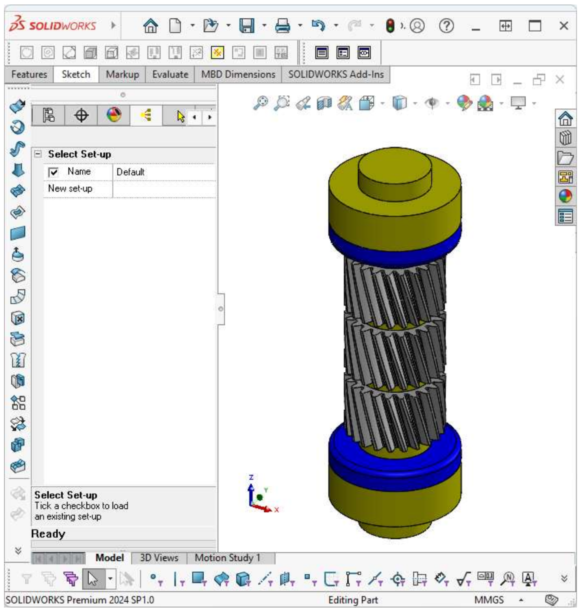


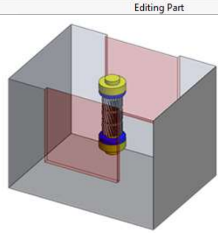


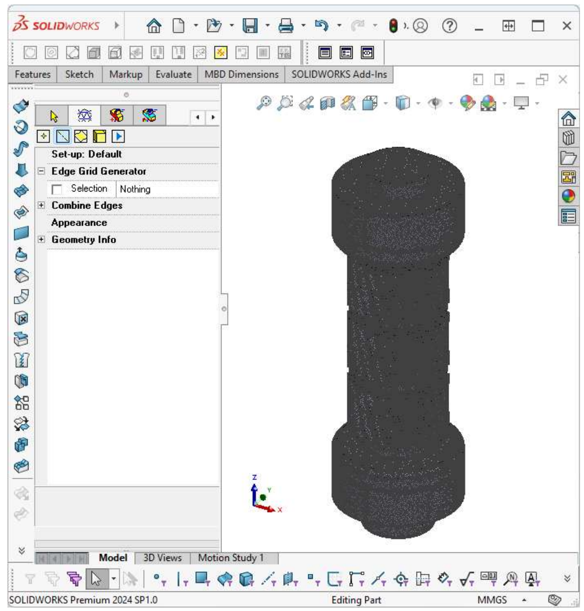
Not possible to electroplate this part to specifications without tooling

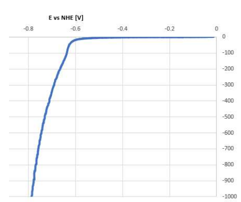
Modelling dispersion coatings

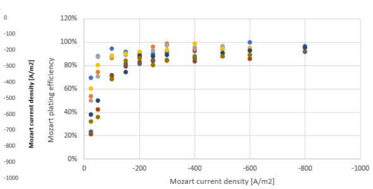
Tooling configuration

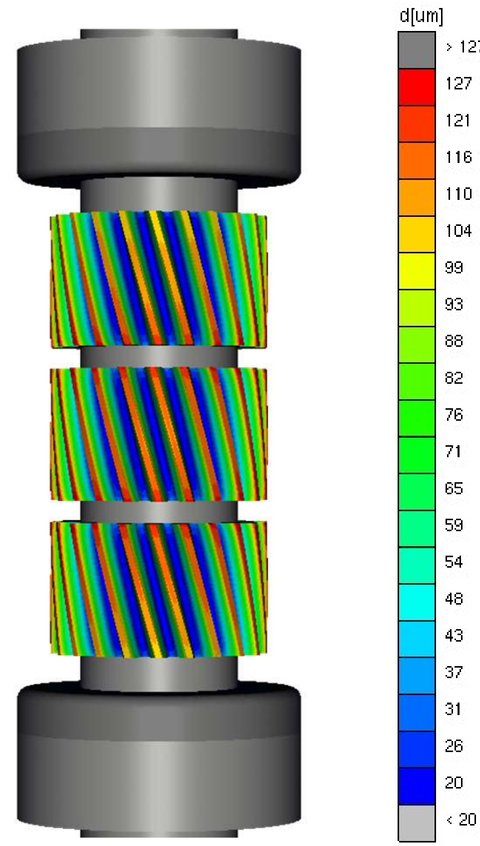












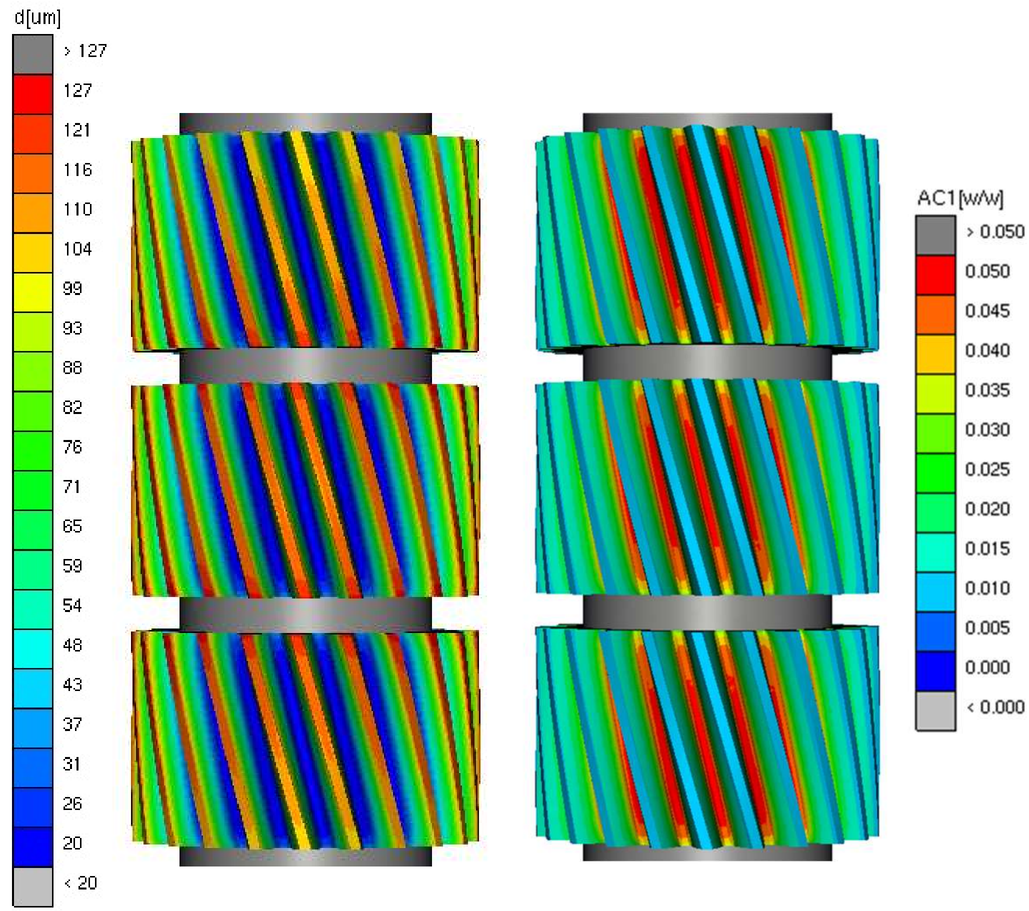
Modelling dispersion coatings

Optimized configuration

- Layer thickness between 20 µm and 127 µm

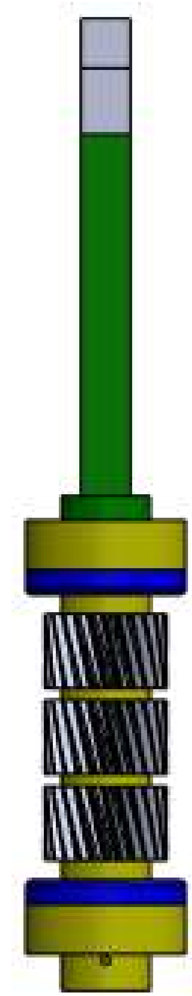
➔ **Part plated within specifications**

- Highest particle content in the grooves, where lowest current density is observed
- 1-2% particle content on tooth surface
- On the tooth surface, main dependency is on current density



Conclusions

- Within the Mozart project:
  - A coating hardness comparable to hard chrome has been achieved
  - Developed a technology to model nano-particle distribution within a nickel dispersion coating
- The real-world demonstrator case highlights the difficulty in achieving uniform particle distribution (= hardness) across the full part surface
- Mastering the plating process and anticipating particle distribution is key to develop counter measures to deliver the desired particle content in the required areas
- Electrochemical modelling is required to achieve a successful hard chrome replacement coating



The electrochemical reference in software & engineering.

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