Healing Metals by Electrochemistry

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- Pores in cellular structure house cells and blood vessels.
- Blood vessel network transports nutrients, minerals and cells to the damage site.
- Bone heals effectively near room temperature (37 °C).
A transported-mediated approach to heal metals

• Parylene D is an electrically-insulating polymer with excellent chemical stability.

• Parylene D is deposited on cellular nickel via a vapor-based process.

PARYLENE D
A transported-mediated approach to heal metals

- Electrodeposition at -1.8 V vs. nickel counter electrode.
- Polymer coating allows selective nickel deposition in fracture locations.

\[ \text{Ni}^{2+}_{(aq)} + 2e^- = \text{Ni}_{(s)} \]
Healing cellular nickel with 3 types of damage

Plastic deformation (P)

Tensile failure (F1)

Scission failure (F2)
Healing after scission failure (F2)

Strength healing efficiency plateaus at 100% after 1,500 J.

Strength of healed scission exceeds material strength in B samples.
Healing after tensile failure (F1)

- Poor segregation of nickel deposits due to distributed strain.

- Strength healing efficiency reaches 104% at 3,500 J.
- Limited recovery of toughness due to low ductility of electrodeposited nickel (27 nm grain size, by XRD).
1) Loading in tension until 3% strain
2) Electrochemical healing
3) Loading in tension until failure

Up to 1.5x improvement in strength compared to non-healed samples
Healing electrical conductivity

- Pristine sample: $0.159 \pm 0.001 \, \Omega$
- Fully ruptured sample: Very high resistance
- Healed sample (1500 J): $0.163 \pm 0.032 \, \Omega$

Electrical resistance can be recovered to within 2.5% of its original value.
Our approach enables low-energy metal healing

Our work

- Electrochemistry
- Heat-driven precipitation
- Phase transition
- Diffusion + phase transition
- Localized joule heating

• Electrochemistry enables **transport-mediated healing** in cellular metals.

• We enable rapid, effective, low-energy, room-temperature healing of cellular metals.

  • 100% recovery of strength after scission failure and tensile failure.

  • Up to 1.5x strengthening of plastically-deformed cellular nickel.

  • Low-energy healing: a cleaved sample can be healed up to **162** times with a smartphone battery.

  • Full recovery of electrical conductivity after fracture.

• Further developments (e.g. autonomous healing) can revolutionize how we design metal parts in aerospace vehicles and robots.
Low-Energy Room-Temperature Healing of Cellular Metals

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