

□ □ **María Cecilia Poletti, Ilse Letofsky-Papst, Annette Mütze**

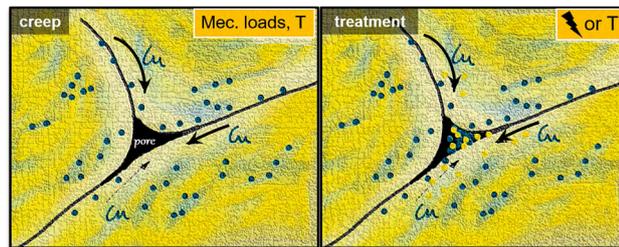
Metals that Heal Themselves: Unlocking the Power of Electricity

Materials with healing capabilities are no longer mere science fiction; however, how and when do alloys heal?

Polymers and advanced concrete can heal upon or even during damage in response to external stimuli, such as changes in temperature. But what about metals? Can they heal themselves? If so, which types of external stimuli can activate the healing processes? Interestingly, some metallic materials, such as aluminium alloys, have demonstrated self-healing capabilities. However, this field of research is still in its early stages, especially in comparison to concrete and polymers, which are based on fundamentally different physical mechanisms. One challenge is that heat, while used for starting the healing process, can also change the alloy's microstructure in undesirable ways. That's why scientists are now investigating alternative external stimuli that enable healing in metallic systems without compromising their structural integrity.

OBJECTIVES, HYPOTHESIS AND THE NEED FOR INTERDISCIPLINARITY

ELISHA (ELectric current effects on the Self-Healing of Al alloys) is the project of an interdisciplinary research group investigating the self-healing properties of aluminium alloys. Our goal is to support the development of highly durable products where components are exposed to temperatures and mechanical stress. We investigate autonomous (during service) and non-autonomous (triggered by external agents) self-healing properties. Our work focuses on how certain elements – like copper, silicon, or iron – can move through the material by diffusion to repair small defects (micrometre-pores), as shown in the illustration in Figure 1.



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Figure 1. Schematic illustration of the self-healing phenomenon driven by diffusion of atoms. Source: Ilse Letofsky-Papst, Annette Mütze, María Cecilia Poletti

We aim to identify and produce microstructures that promote self-healing and to use and control electric currents to heal creep pores in aluminium alloys. Indeed, we hypothesise that applying electric currents can accelerate atomic diffusion to decrease the self-healing temperature. Specifically, we aim to heal damage below 100°C using pulsed electric currents.

We are scientists dedicated to materials science and engineering with a specific focus on atomistic modelling (Lorenz Romaner and Christoph Dösinger MUL), microscopy (Ilse Letofsky-Papst, FELMI/TU Graz and ZFE Graz) materials production, modelling and characterisation (María Cecilia Poletti and Anika Wiebogen, IMAT/ TU Graz), and electromagnetics (Annette Muetze, EALS/TU Graz). Our group also comprises international partners from Politecnico di Milano (Elisabetta Gariboldi and Antonio Grande).

THE STRATEGY AND INITIAL STEPS REVEALING SELF-HEALING BEHAVIOR

To achieve our goals, the first step is to identify the chemical elements in aluminium that either slow down or help heal the damage. Theoretical calculations of the potentials of different

crystallographic configurations indicate which solutes are likely to segregate to grain boundaries and pores rather than remain within the aluminium grains. Figure 2 highlights these solutes in green in the periodic table. Based on these first calculations, we selected Cu and began with the Al-Cu system, with Cu concentrations up to 5wt%.

Secondly, we produce our materials using a mixture of pure Al and Cu powders using laser powder bed fusion. Samples are then produced layer by layer, in a process commonly known as 3D manufacturing. This process produces an unstable and heterogeneous distribution of elements, creating chemical gradients. The gradients, rapid solidification and cooling increase the driving force for diffusion. Additionally, we perform post-heat treatments to reduce the amount of free Cu by promoting the formation of intermetallic phases in the solid state.

Next, we expose the produced and heat-treated samples to creep conditions, i.e. elevated temperatures and mechanical loads and compare their performance with conventional materials. Initial results indicate that the creep resistance of the

material, where Cu is not free to diffuse (after heat treatment), is lower than in the as-produced condition. In the next years, we will expose the creep (i.e. damage) in the material to external temperatures and/or electrical currents. We characterise the self-healing potential after damage using direct optical and electron microscopy to obtain

information about the intermetallic phases, crystal structure, crystal defects, pores and cracks. Additionally, we obtain information about the microstructure using X-ray diffraction and dynamic mechanical and thermal analysis. The acquisition of a special sample holder, which allows simultaneous heating and biasing, will enable

in situ observations during healing in the transmission electron microscope.

Finally, we will develop physics-based mathematical models to describe and predict the damage and healing of Al-alloys under different service and post-treatment conditions. We are optimistic about making significant progress in self-healing alloy technology. ●

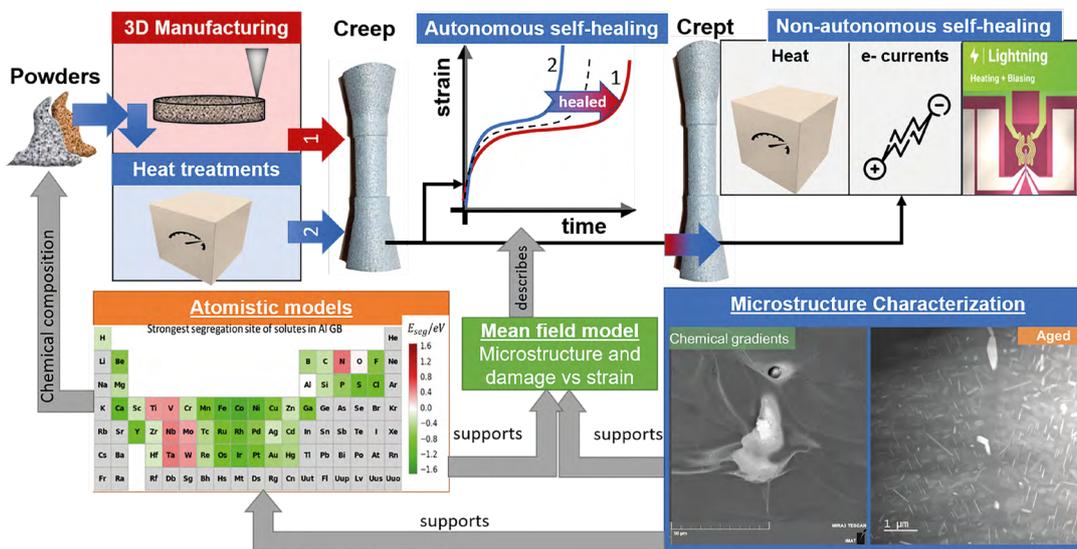


Figure 2: First results and general strategy for materials production, treatment, testing, characterisation, healing and modelling. Source: Ilse Letofsky-Papst, Annette Mütze, Maria Cecilia Poletti



Ilse Letofsky-Papst studied technical physics at Graz University of Technology and earned her doctorate in materials science at the University of Leoben. She works at the Institute of Electron Microscopy at TU Graz. Her research focuses on transmission electron microscopy (TEM), with a specialization in analytical electron microscopy, high-resolution imaging, electron diffraction, cryo-electron microscopy, and *in situ* electron microscopy.



Annette Mütze received the Dipl.-Ing. and the Dr.-Ing. degrees in electrical engineering from Darmstadt University of Technology, Darmstadt, Germany, in 1999 and 2004, respectively, and the Diploma in general engineering from the Ecole Centrale de Lyon, Écully, France, in 1999. Since 2010, she has been a full professor at Graz University of Technology, Graz, Austria.



Maria Cecilia Poletti studied chemical engineering at UNComa, Argentina, and got her doctorate in 2005 at TU Wien, Austria. She focuses on applied and fundamental research in metallic materials, analysing phenomena in alloy processing such as solidification, plastic deformation, and phase transformation. From 2017 to 2025, she directed the Christian Doppler Laboratory for high-performance alloy design via thermomechanical processing.