communications materials

Research highlight

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Chemically-simple magnesium alloys for biomedical applications

There is growing interest in reducing the chemical complexity of engineering alloys. Here, an Mg-Ca alloy for use in bone fixation has less than 1 weight % calcium, and achieves strength and ductility superior to many conventionally-processed magnesium alloys.

Chemical composition is one of the key parameters that determines alloy properties. The prevailing approach to alloying over the centuries has been to add elements, to tune microstructure and performance. This has led to substantial property improvements in all classes of engineering alloys. However, there are clear drawbacks to complex alloy chemistry – not only does cost increase, but they can become harder to process, and recycling or disposal at end-of-service more challenging. There has, however, been an increasing number of reports of "ultra-lean" or "plain" alloys[1]. These alloys have simplified chemistry, and make the best use of their alloying components and processing to control structure and properties.

One area where chemically simple alloys are appealing is for biomedical implants. Low elastic modulus metals are commonly used as load-bearing implants, as polymers do not typically have sufficient strength. However, certain alloying additions might result in an immune response from the body, causing rejection of the implant. And for bone fixation, it is desirable that the implant degrades in the body so that a second operation is not required to remove the implant, in which case the dissolved alloy should not antagonize the body.

Magnesium alloys are attractive biomaterials as they have a low Young's modulus, mitigating stress shielding, and magnesium is non-toxic in the body. However, traditional magnesium alloys require substantial alloying additions to improve their strength and ductility, and many of these should not be introduced to the body. Now, Tatiana Akhmetshina, Jörg Löffler, and colleagues, report ultra-lean Mg–Ca alloys with potential for use as implant materials[2]. They study a series of extruded alloys with 0.2–0.6 weight % calcium, achieving an ultimate tensile strength (UTS) of 380–420 MPa and up to 36% ductility (Fig. 1).

"This research has a long history, and it took us more than a decade to move from magnesium alloys with rare-earth elements to Mg–Zn–Ca alloys with high zinc content (approx. 5 weight %), to lean Mg–Zn–Ca alloys, and finally to ultra-lean Mg–Ca alloys," comments Löffler. "We are able to produce magnesium alloys that achieve by far the highest UTS per weight % of alloying elements, with a two- to ten-fold increase in UTS without compromising ductility."

Achieving this performance while ensuring biocompatibility required careful control of chemistry. "To ensure good biocompatibility we wanted to have the magnesium content as high as possible, but needed some alloying elements to enhance strength and ductility. We focused on calcium, as it is an essential mineral and micronutrient to the body (similar to magnesium) and therefore biocompatible". Indeed, the small amount of calcium is vital to the alloy's properties; it promotes the formation of the Mg_2Ca Laves phase upon precipitation, and these precipitates cause high strength when located within the grains. In alloys where they are located at grain boundaries, ductility is enhanced. Calcium solute also lowers the stacking fault energy, which

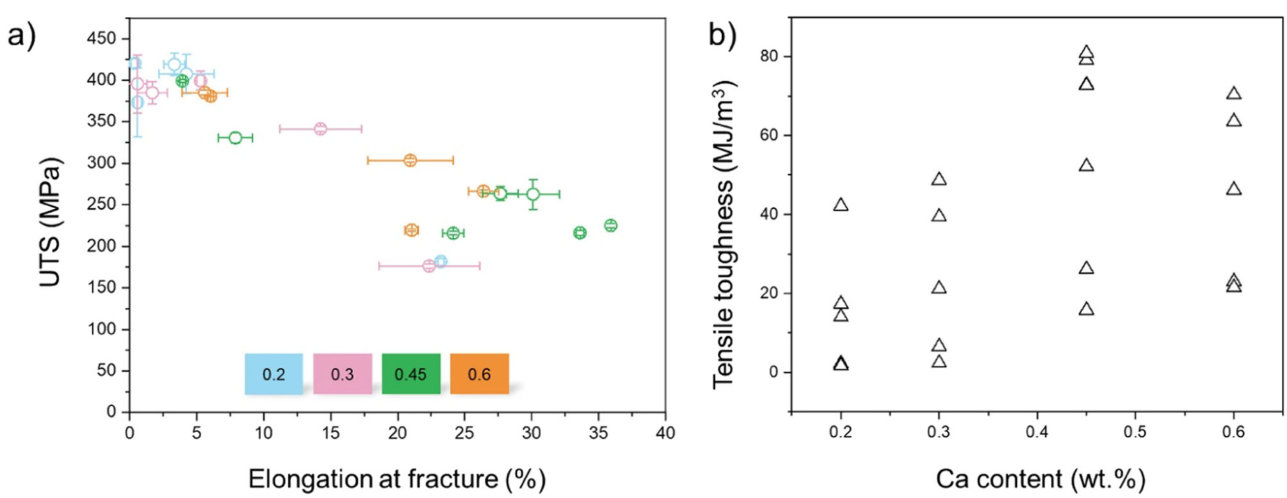

Fig. 1 | Mechanical response of ultra-lean Mg–Ca alloys. a Tensile response. Colored boxes indicate the weight % of calcium ('UTS' is ultimate tensile strength). **b** Tensile toughness, defined as the product of UTS and elongation to failure, of each composition. (Figure reproduced with permission from ref. 2, copyright Elsevier 2024).

equalizes the energy barrier for pyramidal-to-basal and basal-to-pyramidal cross-slip, reducing mechanical anisotropy.

Further work is needed to prove the capabilities of these ultra-lean alloys. Explains Loeffler: "we are currently researching in detail the electrochemical properties of these alloys, and have produced implants based on our ultra-lean Mg–Ca concept. In fact, we are testing these implants in vivo in a large-animal (sheep) study."

The type of ultra-lean alloys reported here can contribute to the emerging consideration being given to sustainable alloys[3]. Chemically simple metals demonstrate how re-assessing the contribution of each element in an alloy can lead to improved properties by judicious processing and composition optimization.

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