High Strength Biodegradable Mg-based Materials for Medical Application

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Introduction

Magnesium (Mg) based biodegradable materials are a new generation orthopedic implant materials that are considered as promising substitutes to permanent implants and eventually degrade completely in biological medium. Mg alloys offer a significant benefit over permanent implant materials including:

I. The Young's moduli (41–45 GPa) and density of Mg and Mg alloys (1.74–2.00 g/cm3) are close to that of cortical bone, thus they effectively avoid the stress-shielding effect

II. Mg is an important element in the human body and can activate a variety of enzymes involved in metabolic processes

III. Mg degrades into Mg ions (Mg^{2+}) which can be absorbed by the surrounding tissue or can easily be excreted

Recently, high purity magnesium has been used in preclinical non/ or low load-bearing applications. However, there are still many technical challenges impeding the application of biodegradable Mg and Mg alloys in orthopedics for load-bearing indications (Fig. 1).

Although the challenge of low initial strength can be overcome with alloying and grain refinement induced by severe plastic deformation, most Mg alloys are still too soft to be used for load-bearing indications, and the degradation rate might be further enhanced (e.g., Mg-Al and Mg-Zn alloys). This is related to the low solubility of Mg for most alloying elements and thus the formation of precipitates which are nobler than the Mg matrix and act as cathodic sites for micro-galvanic corrosion.

The project aims to overcome the difficulty to develop Mg-based materials having simultaneously an excellent combination of high strength, sufficient ductility and low degradation rates.

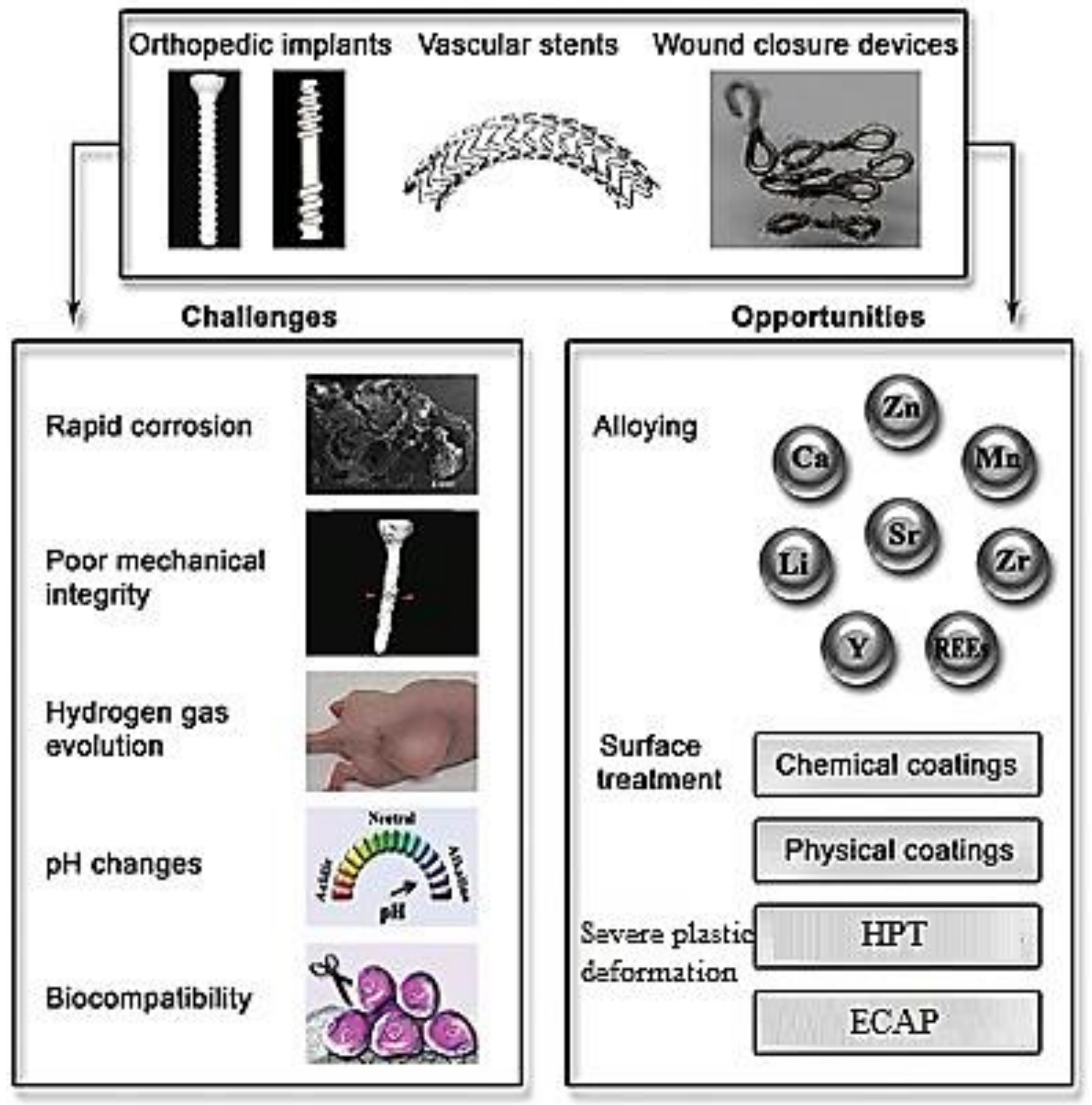

Fig. 1. Challenges and opportunities for biodegradable magnesium alloys

Objective

The major aim of this project: Development of a Mg-based composite enabling load-bearing medical applications by having an excellent combination of sufficiently high strength (>400 MPa targeted) and low corrosion rate.

Mg-Fe Composites

Main ideas

Combining the advantages of both, **pure Mg** (low elastic modulus, osteoconductive effects) and **pure Fe** (strength, low degradation rate)

Main challenges

-Fe and Mg are immiscible under equilibrium conditions and Mg boils way before Fe melts

-A large difference in their electrochemical potentials which causes galvanic coupling and extreme corrosion rates

Hypothesis

Creating a nanometer-scale layer structure of Mg and Fe and consequent decreasing in galvanic corrosion rate by:

1. blocking the electrical contact via corrosion byproduct

2. hinder exchange of the electrolyte inside the narrow Mg channels (increase pH value)

Methodology

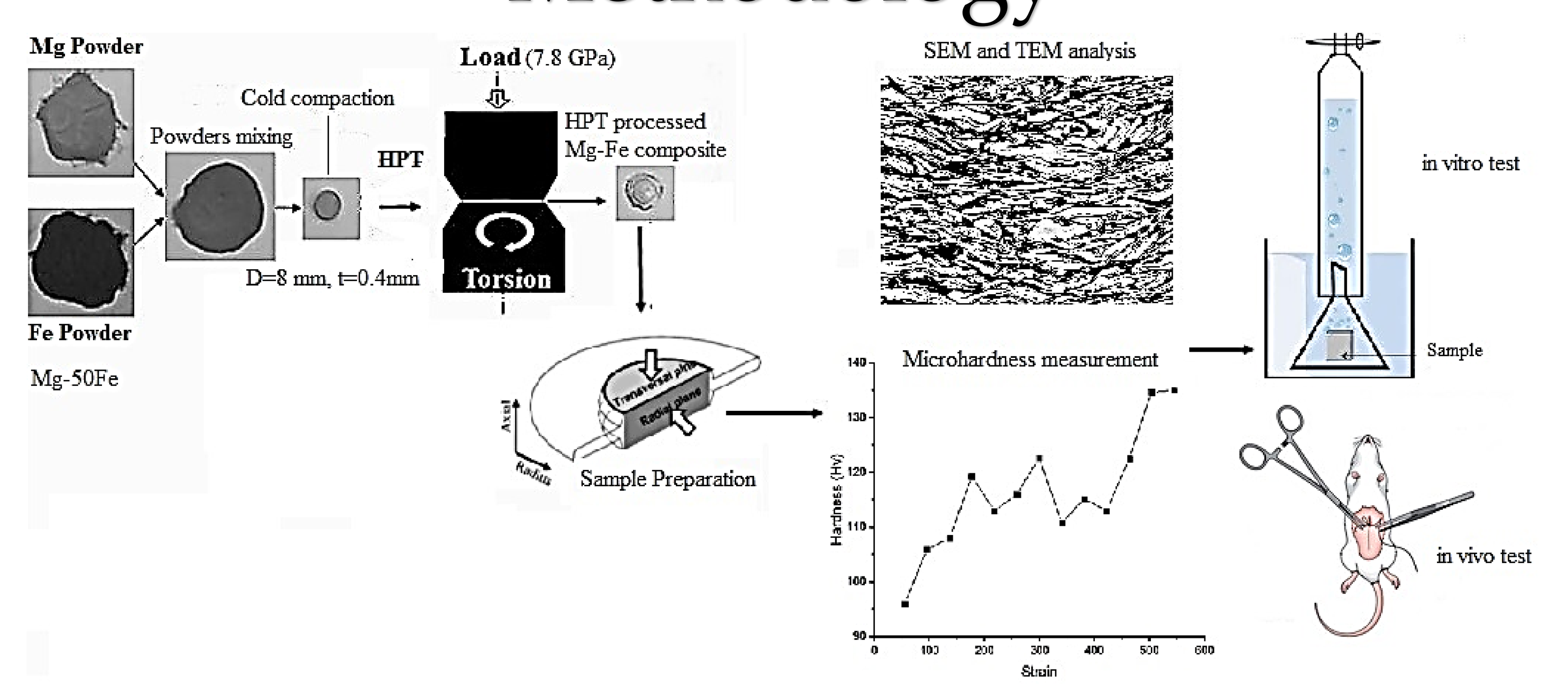

Fig. 2. Schematic illustrating the experimental work to develop Mg-Fe composites

To develop the proposed composites the following experimental steps are scheduled:

1) Producing Mg-Fe composite by mixing of pure Mg and Fe powders with different volume ratio (30, 50, 70 vol% Fe)

2) Consolidation of powders into discs and applying severe strains by HPT using various process parameters (e.g., different strains and HPT temperatures)

3) Microstructural analysis using electron microscopy (SEM, TEM)

4) Mechanical property testing (microhardness, compression tests)

5) Evaluation of degradation behavior by in-vitro (immersion test in PBS solution) and in-vivo pilot (small animal model)

Preliminary results

In Fig. 3 representative microstructures and distribution of Mg layer thickness (or Fe phase spacing) of the deformed Mg-50Fe composites are displayed. As can be seen HPT causes a significant refinement and alignment of the two phases along the shear direction and the Mg layer thickness is considerably reduced (~400 nm) by increasing deformation temperature and strain.

As can be expected from the composite structures, a reduction of the composite phase spacing induces a significant hardness increase. Due to the radial dependence of the shear strain in torsion, a slight gradient in hardness across the HPT disk can be measured (Fig. 3)

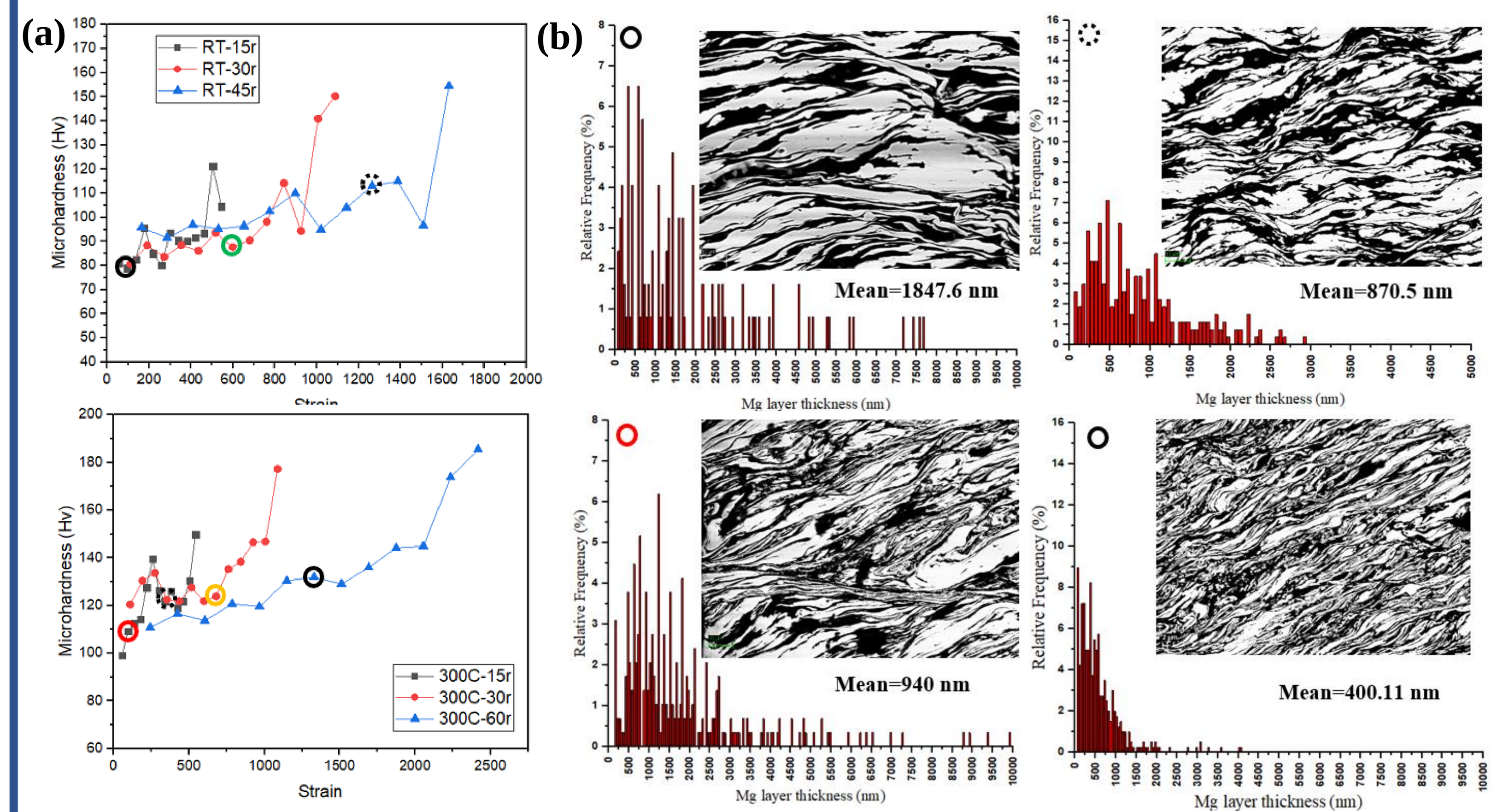

Fig. 3. a) Microhardness of the Mg-50Fe composite as a function of applied strain at RT and 300°C, b) Backscattered electron images of deformed Mg-50Fe composites

Fig. 4 shows the hydrogen gas (H_2) evolution (i.e., a measure for the Mg degradation rate) of Mg-50Fe composites with different Fe phase spacing. The degradation rate decreases dramatically as the Fe phase spacing of the composite structure becomes decreases.

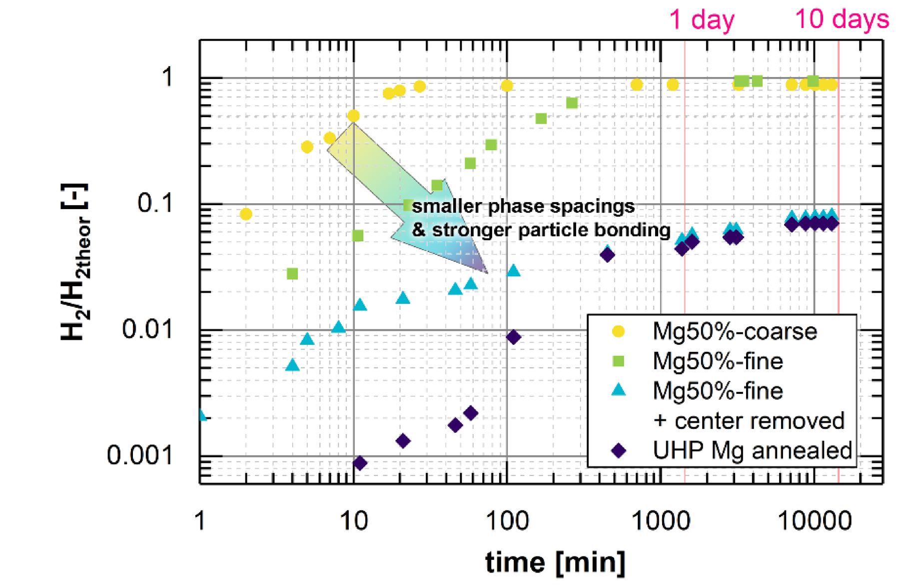

Fig. 4. Hydrogen gas evolution of Mg-50Fe composite with different phase spacings (coarse and fine). Data from obtained on UHP Mg is given as a reference.

References

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