Executive Summary

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Project “Smart magnetic shape memory alloy composites“

This research aimed to develop new polymer composite materials, containing thin embedded metallic wires or powders made of Magnetic Shape Memory Alloy (MSMA), and to explore their potential to provide damping as well as alternating deformation at high frequency in structural parts.

Shape memory alloys are smart materials that are able to dissipate energy when strained and change their shape in a controlled manner when subjected to an external stimulation. This behaviour generally results from both a motion of mobile twins and a solid-state phase change from a parent phase at higher temperature to a martensitic phase at lower temperature, respectively. The slow kinetics of heat transfer, however, limits the actuation frequency of thermal activated shape memory alloys. Piezoelectric materials, alternatively, exhibit high actuation frequencies but only marginal actuation strains. Ferromagnetic shape memory alloys (MSMA) are a sub- group of thermal shape memory alloys that exhibit strain changes at constant temperature in a magnetic field. This allows actuation frequencies of up to 2 kHz, making MSMA promising candi- dates for applications requiring damping and isothermal, high frequency actuation. An interest- ing MSMA is Ni-Mn-Ga with a magnetic field induced strain (MFIS) caused by twinning of theoretically up to 10 %. Polycrystalline Ni-Mn-Ga, however, is brittle and grain boundaries hin- der twinning and suppress the MFIS. Single crystals of Ni-Mn-Ga, on the other hand, are expen- sive to produce.

In this work, we proposed to overcome the limitations of bulk Ni-Mn-Ga by exploring the development of composites of Ni-Mn-Ga powders, fibres and single crystalline rods embedded in an epoxy matrix. In powders and fibres with grains as large as the element diameter, twin bounda- ries span across entire grains and are mobile. Such elements can then be embedded in a polymer matrix to form a material that can be handled and shaped easily. Several main aspects were ad- dressed: Characterisation of the different Ni-Mn-Ga elements and epoxy matrix systems, tailoring of the interfacial properties, optimisation of the composite microstructure and processing, and finally evaluation of the potential of these composite materials for damping and actuation. Annealing of Ni-Mn-Ga powders and melt-spun fibres resulted in single crystalline particles and bamboo-structured fibres that showed stress induced twinning. The fibres were in general rather brittle and their failure of a statistical nature. The stiffness of the epoxy systems used as matrix was, depending on their glass transition temperature, considerably different, from 2.4 to 2800 MPa. This allowed evaluating the different requirements on the matrix for each of the appli- cation as damper or actuator. Interfacial investigations demonstrated that a silane treatment of Ni-Mn-Ga elements with smooth surface structure improved adhesion with epoxy matrices, in turn leading to a more durable material response.

Ni-Mn-Ga powder and fibre-based composites were produced successfully by casting and vacu- um infusion, respectively. Both composites types exhibited an increased damping behaviour by a factor 2 to 5 caused by stress induced twin boundary motion in the Ni-Mn-Ga elements when annealed and in the martensitic phase. This additional dissipative effect was, however, hidden in composites where the matrix had pronounced viscoelastic behaviour. Due to the larger rein-forcement effect of fibres and thus larger dissipated energy compared to that of powders, the potential of fibre composites for damping applications was found to exceed that of powder com- posites.

Ni-Mn-Ga single crystalline rods showed large magnetic field and stress induced stains, up to about 5%. Their magneto-mechanical behaviour was simulated successfully using a material model developed in this work. Model composites with single crystalline Ni-Mn-Ga rods embedded in an epoxy matrix demonstrated a good potential for magnetic field induced actuation and illus- trated the requirement of a careful matching of the matrix stiffness to enable large deformations. For high frequency actuation with adequate actuation strains, it was found to be essential to select elastic, low modulus polymers as matrix material. In that case, strains above 4% could be achieved with composites containing only 10% MSMA in volume. The implementation of the pro- posed material model into a finite element code, together with the mechanical properties of the matrix, allowed predicting the magnetic field induced strain of unidirectional MSMA composites as a function of volume fraction, geometrical arrangement as well as matrix and MSMA proper- ties.

Finally, this work allowed us to demonstrate the potential, but also the limitations of FSMA com- posites for damping and actuation.