MAGNETOMECHANICAL EFFECTS IN NI-MN-GA/POLYMER COMPOSITES

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ABSTRACT

Recent results in the field of development of novel magnetoactive polymers using powder of the NiMnGa magnetic shape memory (MSM) alloy are briefly reviewed with regard to their potential for the magnetically controlled mechanical damping and magnetic actuation applications. Emphasis is given to the studies of (i) dynamical mechanical response of the textured MSM-powder/polymer composites subjected to the applied magnetic field; and (ii) magnetically activated rubber-like behaviour of MSM-powder/silicone composites. These studies reveal the transformation behavior and field influence on the damping properties of NiMnGa composites, in the former case; and the manifestation of the fully reversible magnetic field-induced twin boundary motion in the particles, in the latter case. The reversibility of the magnetostrain is explained by the appearance of the local restoration forces in the matrix.

KEYWORDS: NI-MN-GA POWDER/POLYMER COMPOSITES, VIBRATION DAMPING, MAGNETOSTRAIN, MAGNETIC FIELD-INDUCED RUBBER-LIKE EFFECT.

INTRODUCTION

Shape memory alloys are promising materials for mechanical damping as they exhibit a large hysteretic recoverable strain. In turn, magnetic shape memory alloys (MSM), such as prototype NiMnGa, although more brittle, could have an advantage for damping due to mechanism of the stress-induced twin boundary motion which can be tailored by magnetic field. It was already demonstrated at the beginning of 2000th [Feuchtwanger, 2003; Hosoda, 2004] that an enhanced brittleness of MSM can be avoided by embedding it in form of a powder into polymer, such as polyurethane, epoxy resin or silicone rubber. Damping capacity under quasi-static and periodic loadings of NiMnGa powder/polymer composites have been studied by several groups.

On the other hand, magnetic actuation studies of NiMnGa powder/polymer composites are still in their infancy as to date only few reports exist showing very small magnetostrain value achieved by composite, see, e.g., [Tian, 2014]. Very recently, we have developed NiMnGa particles/silicone composite demonstrating a record-breaking value of the reversible magnetostrain [Sratongon, 2018].

The results on vibration damping and actuation capability of NiMnGa/polymer composites are focused in this work.

INFLUENCE OF MAGNETIC FIELD ON DAMPING OF NI-MN-GA/POLYMER COMPOSITES

MSM/polymer composites have been considered for vibration [Aaltio, 2016], [Feuchtwanger 2018], [Nilsen 2018], low-frequency [Feuchtwanger, 2003] and impact damping [Feuchtwanger, 2015]. The stress-induced twin boundary motion, as one of the main mechanism of damping, was confirmed directly or indirectly. This mechanism is largely dependent on the value of stress amplitude applied to composite. Both low and high values of stress amplitude were explored in a dynamic mechanical analysis (DMA) performed as a function of temperature in single cantilever [Nilsen, 2018] or uniaxial vibration loading [Feuchtwanger, 2018] modes. The dissipated energy is characterized in DMA method by the loss angle:

$$\tan\delta = \frac{E''}{E'} \qquad (1),$$

where storage modulus E' describes the effective stiffness and corresponds to the Young's modulus under the assumption that the strain-rate is small; and the imaginary part E'' is a measure of damping properties and the amount of dissipated energy. Figure1 shows a large difference in the damping capacity of composite in comparison to silicone. Using tablets of permanent magnet and yoke, a mini-magnet was designed to produce a magnetic field of 0.34 T inside

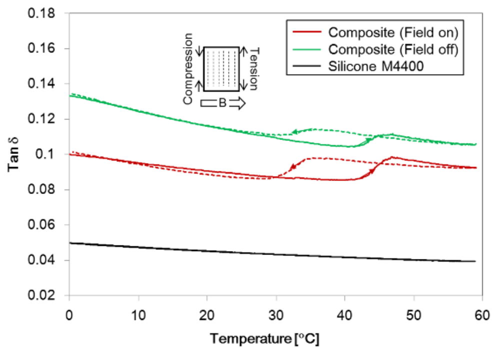

Figure 1: Temperature dependence of loss angle of MSM/silicone textured composite, containing 30vol.% NiMnGa powder, measured by DMA with a stress amplitude of 0.016 MPa without and under magnetic field of 0.34T [Sratongon, 2018].

DMA machine with geometry shown in Figure 1. This figure shows that under applied magnetic field with such a geometry tanδ is essentially reduced in total temperature range. Bearing also in mind a low stress amplitude, 0.016MPa, this fact can be explained by the observed magnetic field induced stiffening of *E´* (not shown here, see also [Nilsen, 2018]). Other interesting fact, namely, the occurrence of tanδ drop at martensitic transformation (MT) and field induced increase of this anomaly, can be explained by the contribution to damping from the magnetic domain wall motion, apparently, exhibiting change due to the domain structure change in particles at MT.

LARGE REVERSIBLE MAGNETOSTRAINS IN NI-MN-GA/SILICONE COMPOSITE

A primary precondition for designing of NiMnGa/polymer composites suitable for magnetic field induced actuation via field induced twin boundaries motions of embedded particles is that the individual particle should be in the martensitic state with a mobile twin structure as in a bulk single crystal. Then, a stiffness-match-matrix, i.e. the polymer which has sufficiently low stiffness, allowing a twin boundary motion in the particles, and enough amount of particles assembled in single chains are needed to expect a substantial magneto-mechanical response of the whole composite. In this case, the embedded magnetically active particles should be crystallographically oriented provided that the easy-magnetization short axes of tetragonal unit cells are aligned along the chains. In contrast to the previous

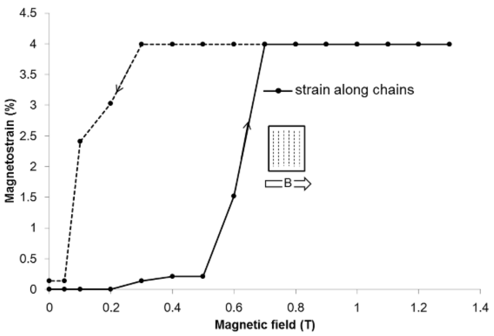

Figure 2: Strain of MSM/silicone textured composite, containing 30vol.% NiMnGa powder, as a function of magnetic field [Sratongon, 2018].

reports [Gans, 2005], [Tian, 2014], those multitude of conditions have been realized for the first time in the present work [Sratongon, 2018]. Figure 2 shows a large value of magnetostrain, 4%, in the field less than 0.7 T. The main key factor in this achievement is a NiMnGa powder containing individual single crystalline grains prepared using TokyoTech special technology. We have observed also the effect of magnetostrain in the individual particle by in-situ measurements with the three-dimensional X-ray micro-computed tomography. Strikingly enough, the magnetostrain response of composite was fully reversible (Figure 2) which means an appearance of the local internal stresses driving twin boundaries back after field removal. Thus, one can name this effect as a magnetically activated rubber-like behavior of MSM/polymer composites.

CONCLUSION

The results show a great potential of MSM/polymer structures for magnetically controlled damping applications, as well as for elaboration of novel magnetic actuators.

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