Giant Magnetostrictive Materials

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The magnetostrictive materials exhibit a strain caused by the orientation of the magnetic moment when exposed to a magnetic field. A new class of magnetostrictive materials discovered by Ullakko *et al.* (1995, 1996) is called Magnetic Shape Memory (MSM) alloys or Ferromagnetic Shape Memory Alloy (FSMA) materials. The thermoelastic martensitic phase transformation in MSM materials produces a low symmetry phase with a large magnetocrystalline anisotropy and highly mobile twin boundaries between the variants. MSM materials exhibit giant magnetic field-induced strain (MFIS) based on the rearrangement of the crystallographic domains (twin variants). In the magnetic field those martensite variants having the easy axis of magnetization along the field, start to grow due to twin boundary motion and become dominant. This process lowers the magnetization energy. The MFIS of MSM materials is unique since it produces a large strain with rather high frequencies without a change in the external temperature. Consequently, MSM materials are potentially important for actuator and sensor applications (Tellinen *et al.* 2002).

The currently best working MSM materials are the near stoichiometric Ni_2MnGa Heusler alloys. Their structural, magnetic and mechanical properties are highly sensitive to the chemical composition and temperature. These have been studied in detail all over the world (Vasil'ev *et al.* 2003, Söderberg *et al.* 2004). Depending on the martensite crystal structure (5M or 7M) one can obtain 6 % or 10 % strain response in a magnetic field less than 800 kAm^{-1} (Murray *et al.* 2000, Sozinov *et al.* 2003), with the optimum frequencies up to 300-500 Hz (O'Handley *et al.* 2001) in the temperature range 150-333 K (Heczko *et al.* 2003) and at ambient temperature the MSM fatigue life can be more than $50x10^6$ shape change cycles.

The schematic behaviour of a MSM material is shown in Fig. 1. In the Ni-Mn-Ga 5M and 7M martensitic structures, the *c*-axis is the shortest crystallographic axis and, simultaneously, the easy axis of magnetization. When the material is exposed to a magnetic field, the variants having *c*-axis along the field become dominant and, consequently, the material contracts in the direction of the applied field. Since this MFIS remains after removing the magnetic field (Fig. 1-1), the actuation movement is only obtained by turning the magnetic field perpendicular to its original orientation (for example, applying a rotating magnetic field, Fig. 1-2) or with an external spring-back load (Fig. 1-3). Consequently, with this way, it is possible to change one single-variant structure to another and to obtain cycling of the giant MFIS.

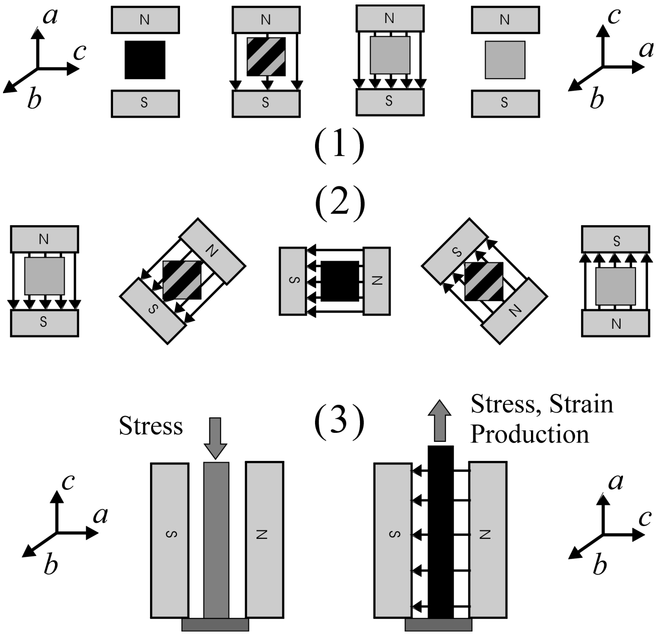

Figure 1.
MSM element in (1) unidirectional, (2) rotating magnetic field and (3) in the actuator. *a, b* and *c* are crystallographic axes of martensite ($c < a,b$), *c*-axis is easy axis of magnetization.

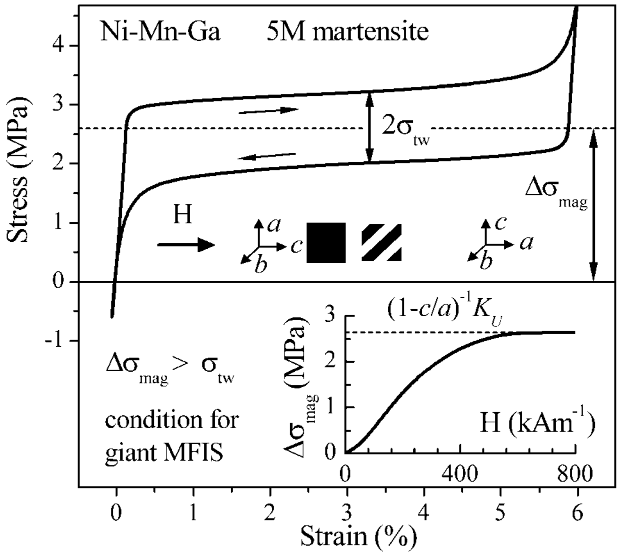

Figure 2.
Compression of MSM element in constant transversal magnetic field H=800 kAm^{-1}. σ_{tw}- twinning stress, $\Delta\sigma_{mag}$-magnetic stress. Insert shows influence of magnetic field on $\Delta\sigma_{mag}$.

Figure 2 represents the behaviour of the MSM material under compressive stress in a constant transversal magnetic field (H). The opposite stress induced by the magnetic field ($\Delta\sigma_{mag}$) is growing with increasing H

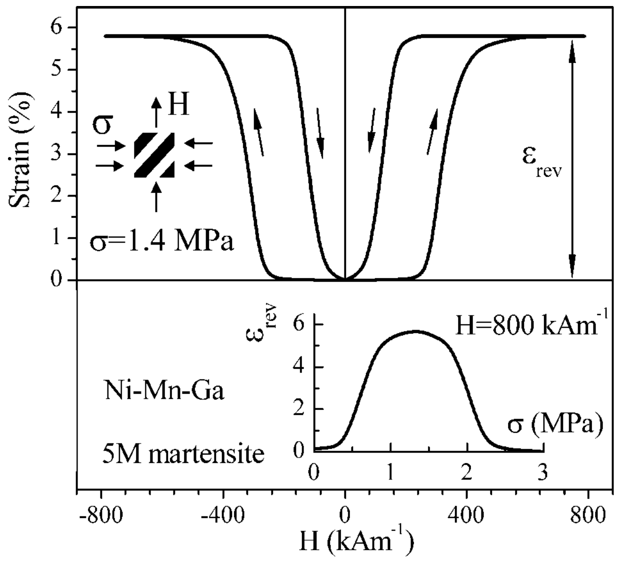

Figure 3.
MFIS at constant blocking stress. ε_{rev}-reversible strain. Insert shows influence of blocking stress on ε_{rev} at constant magnetic field H=800 kAm^{-1}.

and it saturates at $\Delta\sigma_{mag}=(1-c/a)^{-1}K_U$, where K_U is the magnetocrystalline anisotropy energy density of martensite (see insert in Fig. 2). Consequently, the giant MFIS is limited to the materials with rather low twinning stress (σ_{tw}) as the requirement for MFIS is $\Delta\sigma_{mag}>\sigma_{tw}$ (Likhachev *et al.* 2001). The mechanical behaviour of a MSM element in a constant transversal magnetic field (in Fig. 2) resembles the conventional superelastic (SE) behaviour of the austenitic alloys: the large strain related to the stress-induced phase transformation recovers totally when applied stress is removed. However, as in the conventional case of SE behaviour is obtained only in a rather narrow temperature region, the magnetically assisted superelasticity of the martensitic MSM alloys can be realised in the broad temperature range.

The behaviour of MSM alloys at a variable magnetic field and under constant transversal stress is presented in Fig. 3. This behaviour is applied in actuators (Fig. 1-3). The reversible strain (ε_{rev}) observed under these conditions (see insert at Fig. 3) has the maximum at a certain optimal value of blocking stress (O'Handley *et al.* 2001, Likhachev *et al.* 2001). With this optimum blocking stress, the MSM-element is brought back to the initial state when the magnetic field is removed (Fig. 3). In case the stress is below the optimum, it cannot move the twin boundaries back totally and, therefore, the cycling shape change is only partial. Furthermore, if the optimum value is considerably exceeded, this disables the MFIS.

Many other alloy systems (see Vasil'ev *et al.* 2003, Söderberg *et al.* 2004) such as Fe-Pd, Fe-Pt, Ni-Mn-Al, Co-Ni, Co-Ni-Al, Co-Ni-Ga, Ni-Fe-Ga having magnetic and martensitic transformations are at present under intensive investigation as promising candidates for MSM applications.

See also: Magnetic Microwaves: Manufacture, Properties and Applications (100146); Magnetoelastic Phenomena (105014); Magnetoelasticity in Nanoscale Heterogeneous Materials (100136).

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