COMSOL CONFERENCE 2016 MUNICH

HOCHSCHULE KONSTANZ UNIVERSITY OF APPLIED SCIENCES

# 3D-FEM-Simulation of Magnetic Shape Memory actuators

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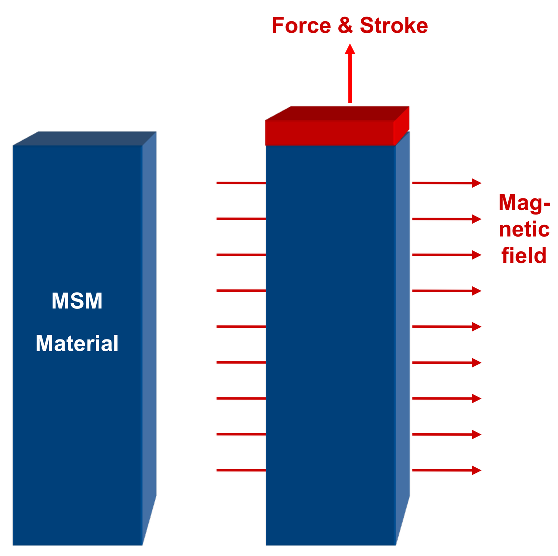
## Introduction

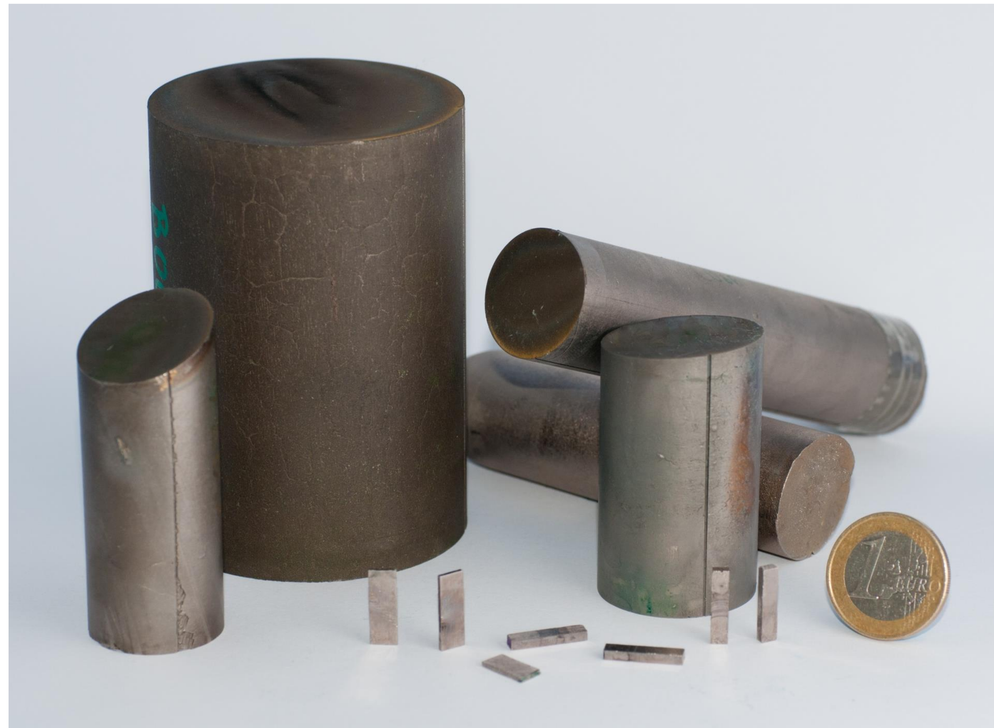
**M**agnetic **S**hape **M**emory (MSM) Alloys are ferromagnetic materials that produce motion and force under moderate magnetic fields. They are typically single crystalline alloys of Nickel, Manganese and Gallium, and are able to produce 6% strain under more than 2 N/mm² external load. Frequencies up to the low kilohertz range can be achieved. The MSM technology has its roots in academia in the mid 1990's. ETO MAGNETIC has developed this material as well as actuator prototypes in recent years to a new level of maturity.




ETO's new **MAGNETOSHAPE®** technology is now ready to conquer the first applications. With its unique technological advantages it shows a clear potential to replace electromagnetic as well as other actuator technologies in future.

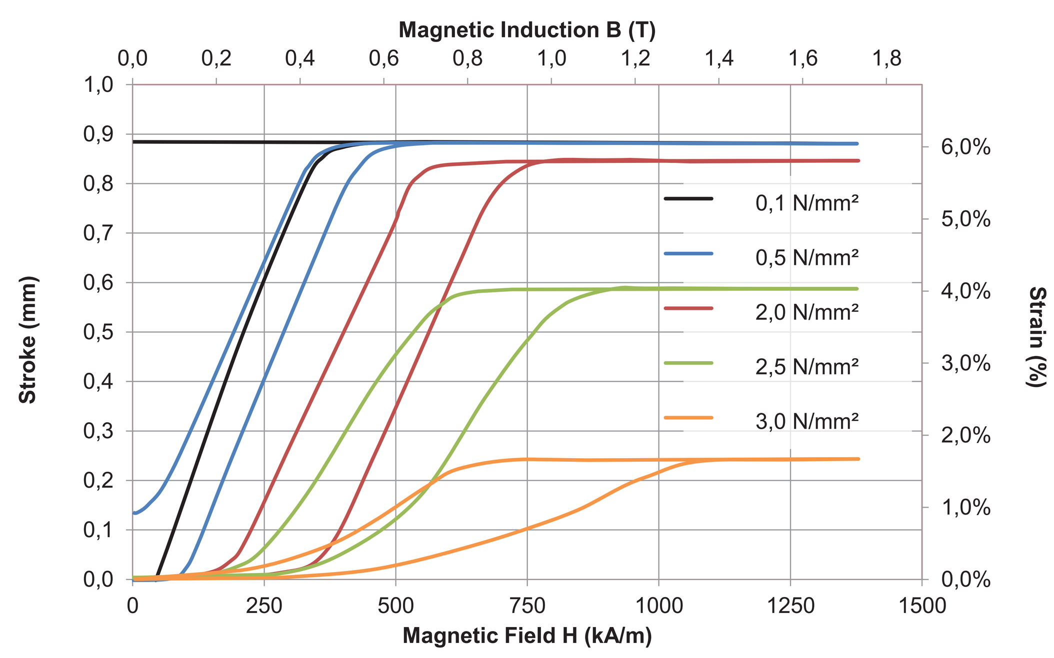
## Production of MAGNETOSHAPE® Material

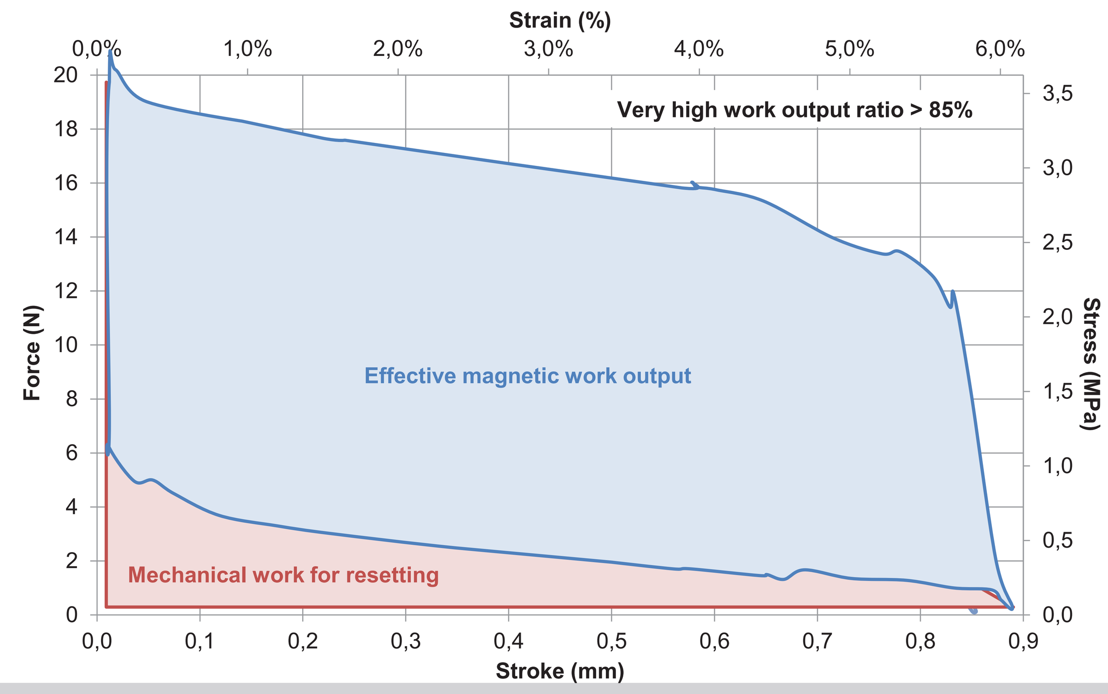
- Raw materials are inductively molten and alloyed.
- Large single crystals are grown using a modified Bridgman process.
- The crystals are heat treated for homogenization and microstructure formation.
- The crystal orientation is measured using X-rays.
- The crystals are cut into rectangular elements.
- The elements are trained.



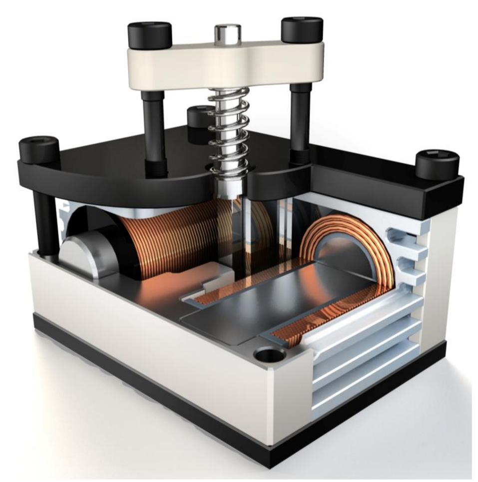
## Technical Data of MAGNETOSHAPE® Materials

| MAGNETOSHAPE® | |
|---|---|
| Alloy | NiMnGa |
| Field induced strain | 6% under up to 2 N/mm² |
| Blocking stress | up to 3.5 N/mm² |
| Switching field | < 0,6 T (full stroke) |
| Temperature limits | -40°C to 60°C |
| High cycle fatigue | 2×10⁹ (material) |
| Typical element size | 1×3×10 mm³ to 6×6×30 mm³ |
| Magnetic permeability | 2 (hard axis); 50 (easy axis) |
| Frequency | DC to 1 kHz |
| Switching speed | < 1 ms (depending on actuator) |

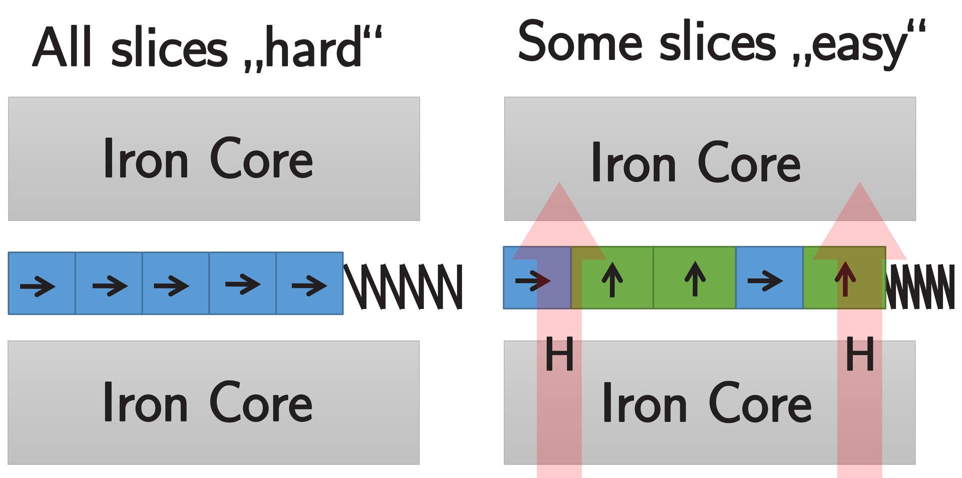


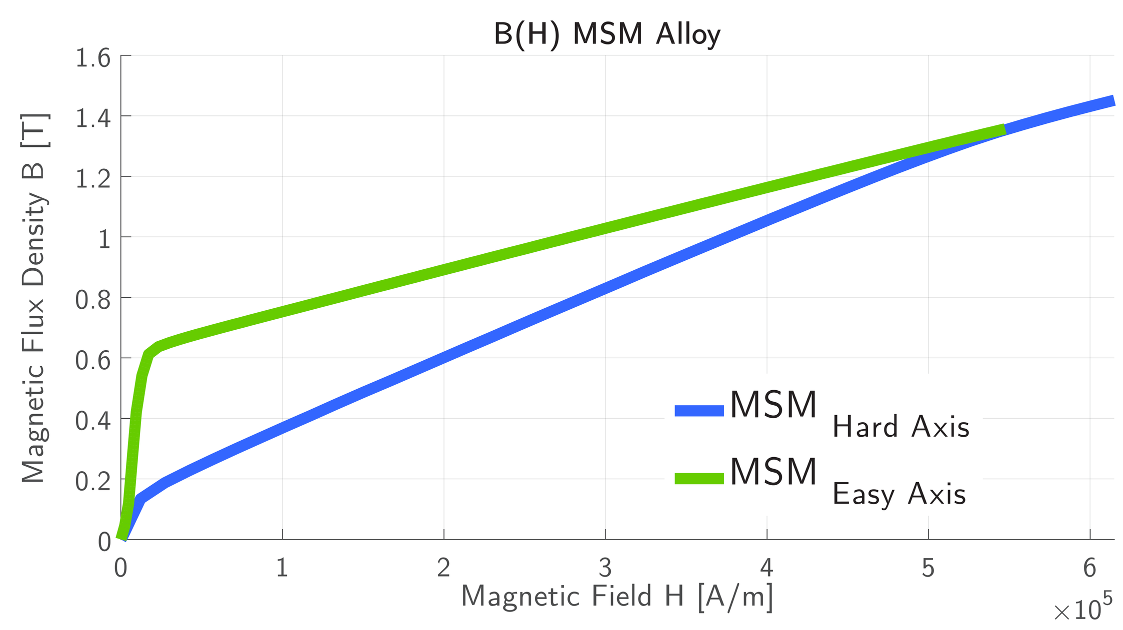

## MAGNETOSHAPE® actuator design and iterative magnetostatic FEM model



- Symmetrically arranged coils
- Geometrically optimized yoke parts made from annealed magnetic steel
- Overall size: 50×35×27 mm³
- Ni-Mn-Ga element: 1×5×15 mm³
- Net force output: ~5 N
- Restoring spring force
- Stroke: 0.85 mm with 2 A
- Switching time: ~3 ms



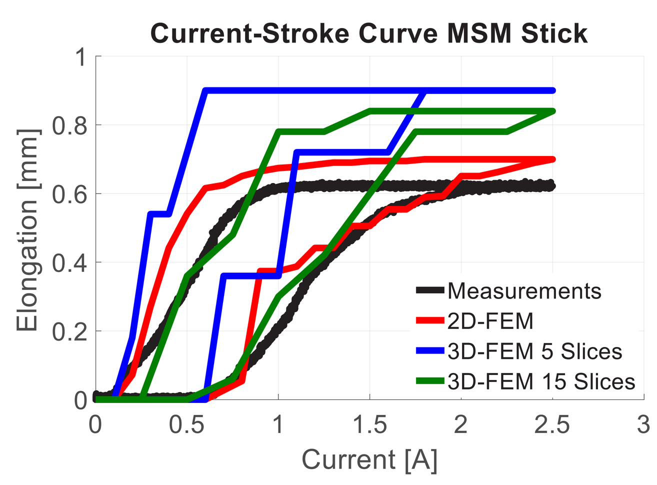

The MSM Element in the actuator is divided in several individual areas. These areas are also called slices. The magnetic characteristic of each slice is anisotropic and therefore each slice has a defined magnetic orientation which is divided in "hard" (blue) and "easy" axis (green). This magnetic orientation is coupled to the crystallographic axis and therefore in this model the slice geometry is coupled as well. In dependence on the stress situation a continuously increased magnetic field can reorient this slice mechanically as well as magnetical. This microscopic change has an impact to the macroscopic shape of the MSM Element (length and width). So far FEM Simulations were realized with 2D-FEM-tools meanwhile this work realizes a 3D-model with COMSOL® Multiphysics where the physical behavior of the MSM element is considered.




- Magnetization curves MSM material have been measured on bulk samples of 2×3×15 mm³
- Magnetic anisotropy measured in compressed and elongated state
- Easy and hard axes exchange orientations
- The FEM model implements a magnetization curve which corresponds locally to the orientation state of the individual slices of the MSM element

## FEM simulation results

- Evaluation with the current-stroke behaviour of the actuator
- The results of the 3D-FEM simulations with COMSOL® are at lower current in a good agreement to existing 2D-FEM simulations and measurements
- 3D-FEM-simulations show hysteresis characteristic of MSM actuators




- 3D Simulation Results show deviation at higher currents that could be caused by too high energy steps between individual slices as well as low slice resolution.

## Conclusion

- 3D-FEM simulation results are presented that demonstrate a possibility of modeling MSM **MAGNETOSHAPE®** actuators.
- Taking into account the anisotropic behavior of MSM materials, as well as an appropriate representation of the twin structure. The flux density within the magnetic circuit of an MSM actuator is analyzed using COMSOL® Multiphysics. The results agree with previous 2D Fem simulations as well as measurements.
- To reduce the divergence between the 3D-FEM-simulations results and the measurements, a increased amount of slices will be necessary. Therefore an automated and adaptive evaluating process is indispensable.