Triple junction modeling with carbide inclusions in MnAl-C

M. Gusenbauer[a], S. Stanciu[a], A. Kovacs[a], H. Oezelt[a], J. Fischbacher[a,c], P. Zhao[b], T. G. Woodcock[b], T. Schrefl[a,c]

ABSTRACT

Local demagnetization fields and exchange coupling between grains have a negative impact on the coercive field of permanent magnets. In this work we quantify coercivity in triple junctions of MnAl-C with embedded paramagnetic and soft magnetic inclusions. Particularly at triple junctions formed at grain boundaries, carbide inclusions are frequently found. Soft magnetic inclusions with a diameter greater than 10 nm, where curling and multi-domain reversal is triggered by adjacent hard magnetic entities, led to only a fraction of the coercive field achieved without the inclusions.

PROJECT PARTNER:

Leibniz Institute for Solid State and Materials Research Dresden

FUNDING:

FWF Austrian Science Fund

FWF: I 5266-N

DFG Deutsche Forschungsgemeinschaft German Research Foundation

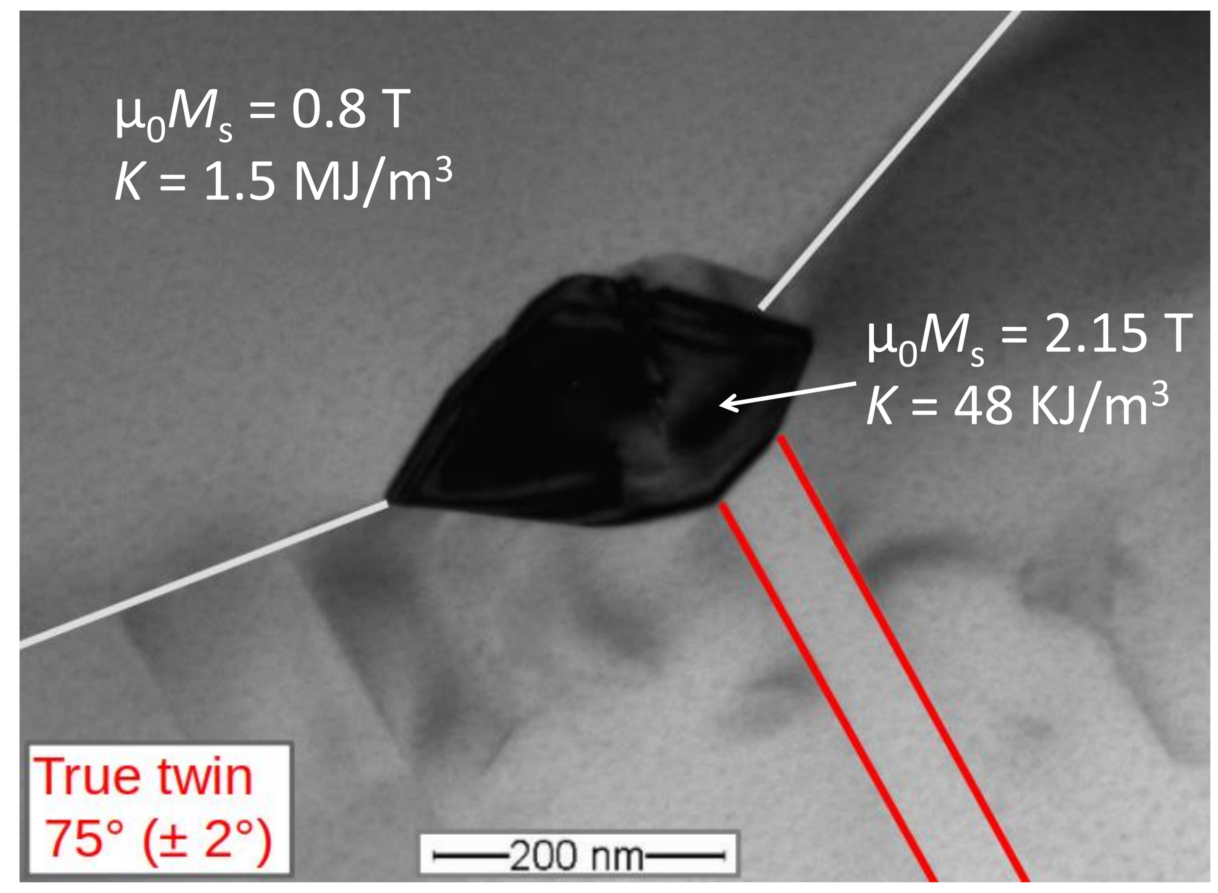
DFG: 326646134

Wissenschaft · Forschung Niederösterreich; FTI-Strategie Niederösterreich 2021-2027; Gesellschaft für Forschungsförderung Niederösterreich; Funded as part of the RTI-strategy Lower Austria 2027

FTI22-D-009

Introduction

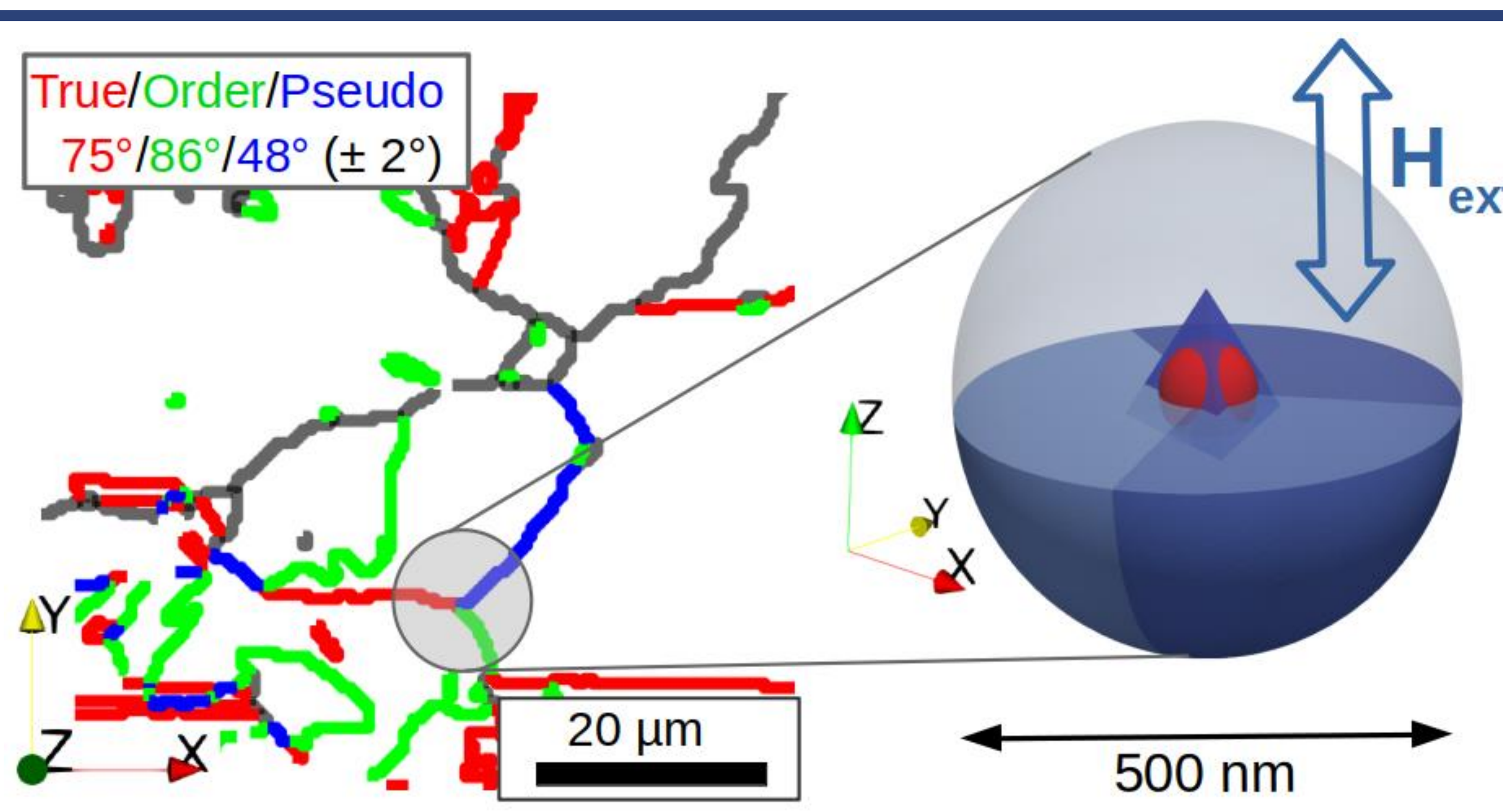
The change in the coercive field caused by carbide inclusions at triple junctions of MnAl-C is unclear. In micromagnetic simulations we assume soft magnetic carbide properties, because of the cubic crystal structure and the multiplicity of easy axes [1]. Therefore we investigate two extreme cases: (i) paramagnetic inclusions or (ii) soft magnetic inclusions with a higher spontaneous magnetization M_s and a lower anisotropy K as compared to the main phase.



We apply extreme cases of the inclusion geometry as well, spheres and regular tetrahedrons. The spherical shape accounts for an idealistic inclusion to investigate the impact of its intrinsic properties, whereas in the tetrahedral shape the effect of sharp edges is included.

Model

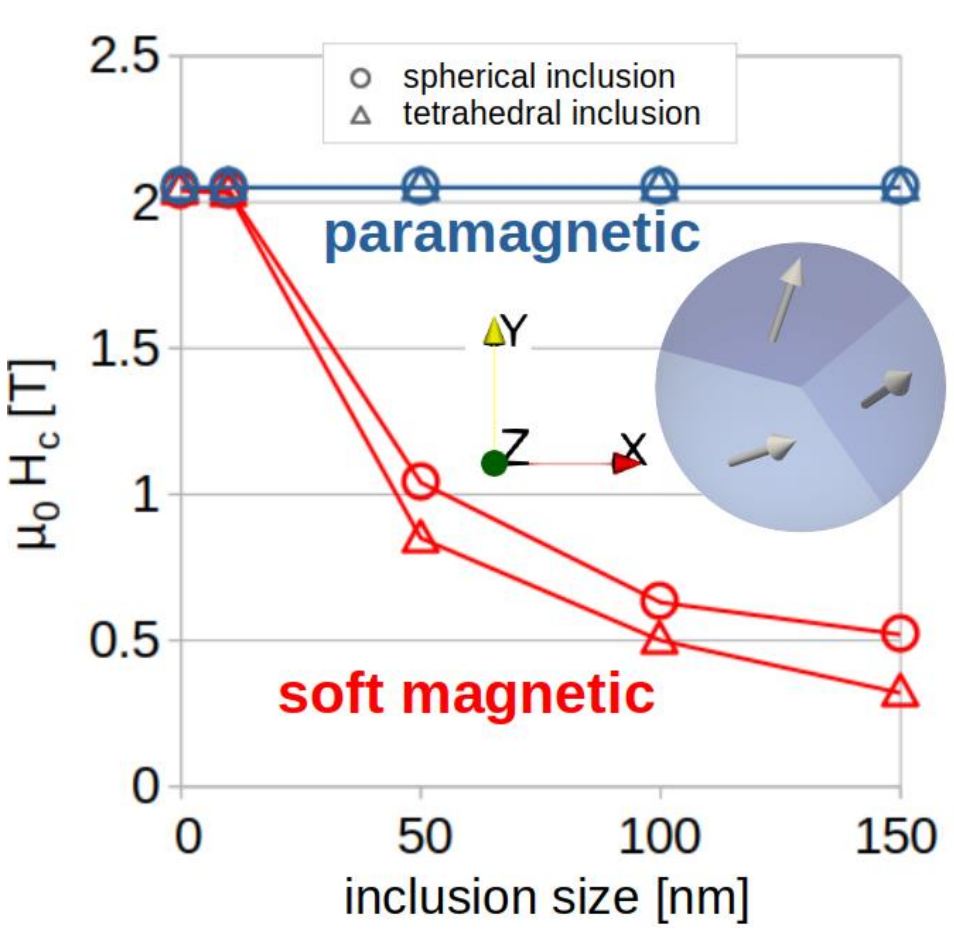
We extract crystallographic orientation information from Electron Backscattered Diffraction (EBSD) data and apply it to a spherical model to avoid demagnetization effects arising from the shape of the model. The model diameter is 500 nm, large enough to allow the formation and movement of domain walls.

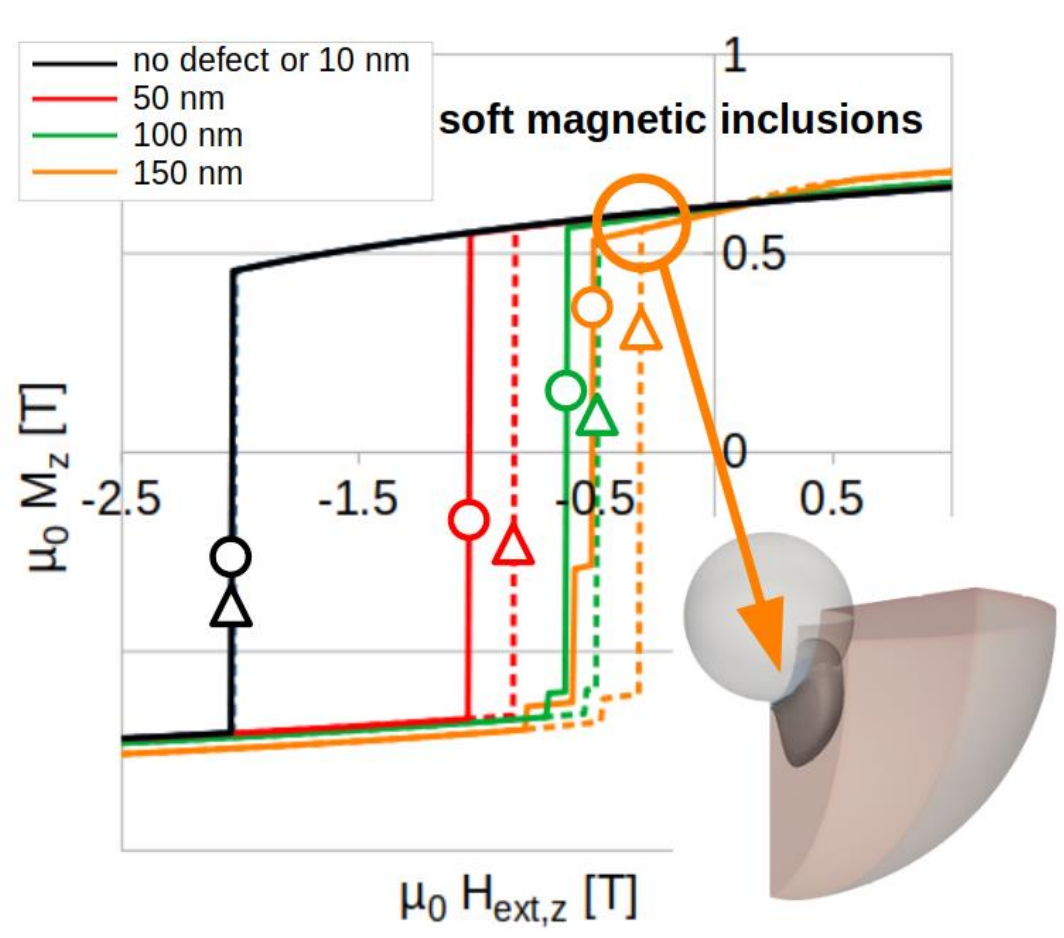


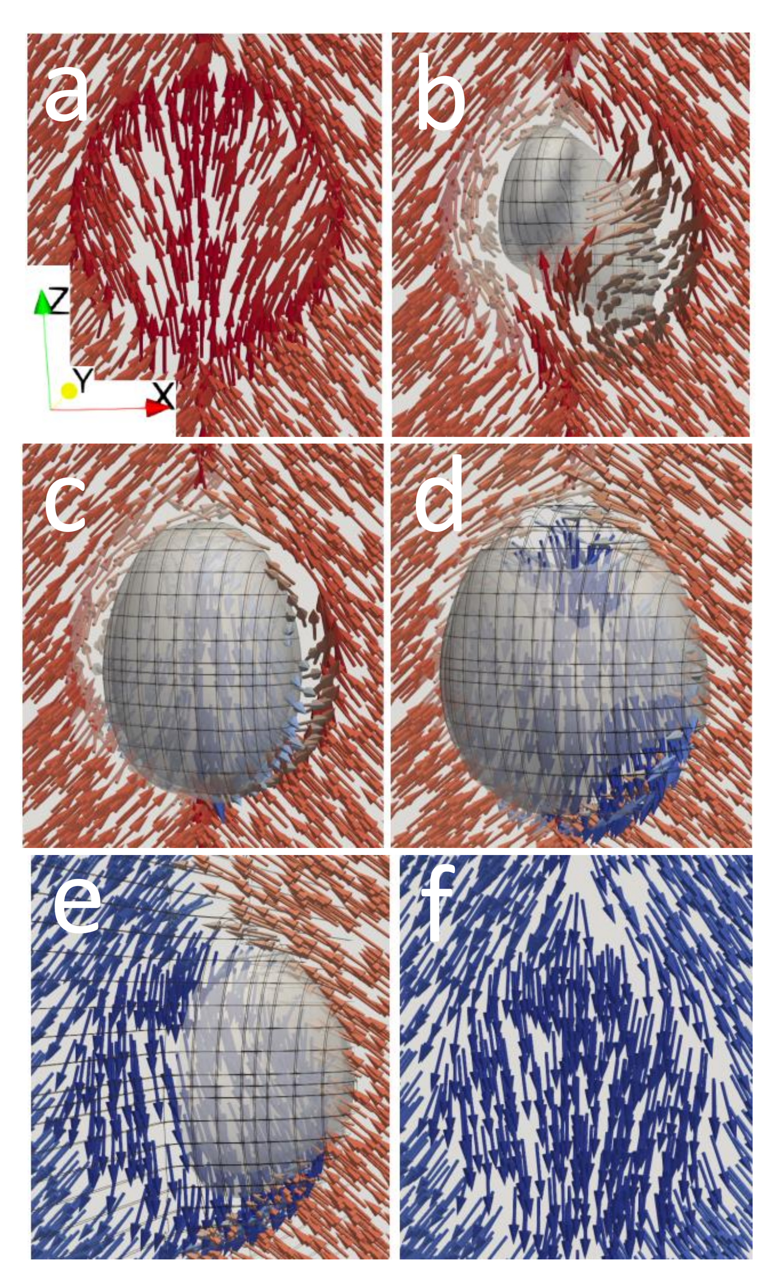
In the center of the model we place soft magnetic or paramagnetic inclusions. We create a finite element mesh of the described model with the pre- and postprocessing software Salome [2] and compute demagnetization curves with inclusion sizes up to 150 nm.

Results

A 500 nm sphere of MnAl-C has an ideal Stoner Wohlfarth nucleation field $\mu_0 H_n$ of 4.71 T calculated by $H_n = 2K/(\mu_0 M_s)$ [3]. If we have a separating interface, in which the easy axes of both entities are misorientated to the external field, the switching field $\mu_0 H_c$ is reduced. Paramagnetic inclusions do not affect coercivity and up to 10 nm inclusion size the soft magnetic inclusions have no influence at triple junctions as well. The geometry of the inclusions and its influence on coercivity get dominant with diameters greater than 10 nm. Here, coherent rotation inside soft magnetic inclusions transforms to curling and multidomain reversal and triggers early nucleation.







On the left: Coercive field $\mu_0 H_c$ as function of inclusion size with an external field applied in z-direction. Easy axis configuration without inclusion is shown as inlay. In the center: Demagnetization curves of the model with soft magnetic inclusions. Early nucleation of the 150 nm spherical inclusion is shown prior the first irreversible step. On the right: Magnetization arrows and domain wall inside the soft magnetic core from (a) initial saturation to (f) full demagnetization.

[a] Department for Integrated Sensor Systems
University for Continuing Education Krems
Dr.-Karl-Dorrek-Straße 30, 3500 Krems, Austria
markus.gusenbauer@donau-uni.ac.at

[b] IFW Dresden
Institute for Metallic Materials,
Helmholtzstraße 20, 01069 Dresden, Germany
t.woodcock@ifw-dresden.de

[c] Christian Doppler Laboratory for magnet design through physics informed machine learning
University for Continuing Education Krems
Viktor Kaplan Straße 2E, 2700 Wr. Neustadt, Austria
thomas.schrefl@donau-uni.ac.at

[1] X.-Y. Wang et al., Journal of Magnetics , 2019
[2] salome-platform.org, last visited on 04/06/2024
[3] E. C. Stoner, E. Wohlfarth, Philosophical Transactions of the Royal Society of London, 1948

University for Continuing Education Krems

Department for Integrated Sensor Systems