Motion of domain walls in ferromagnetic steel studied by TEM – Effect of microstructural features

Mari Honkanen[1], Suvi Santa-aho[2], Nasser Eslahi[3], Alessandro Foi[3], and Minnamari Vippola[1,2]

[1]*Tampere Microscopy Center, Tampere University, Tampere, Finland*
[2]*Materials Science and Environmental Engineering, Tampere University, Tampere, Finland*
[3]*Computing Sciences, Tampere University, Tampere, Finland*

Corresponding author: mari.honkanen@tuni.fi

In a time-varying magnetic field, microstructural features inhibit the movements of the magnetic domain walls (DWs) in ferromagnetic materials. This leads to discontinuous changes in the magnetization generating a signal called Barkhausen noise (BN). A magnetic BN measurement is an important non-destructive testing (NDT) method in industry. In the varying magnetic field, a DW motion is hindered by microstructural features called pinning sites such as grain boundaries, voids, precipitates, and dislocations. To reveal the connection between microstructural features and BN, we studied and visualized the DW motion in ferromagnetic steel by TEM.

Two different microstructures, martensite and pearlite-ferrite, of industrially relevant steel (CF53) were studied. Microstructural features of the samples were studied by SEM-EBSD and TEM. DWs were imaged by TEM using the Fresnel mode. The DWs were moved by using a standard objective lens as a vertical source of the applied magnetic field. The field strength was increased up to ~0.4 T (rough estimation) and several magnetization loops were carried out as in the actual BN measurements.

Quite commonly, BN is linked directly to the sample hardness. A BN outcome (commonly used feature root-mean-square, RMS) from both martensite and pearlite-ferrite was, however, similar even though martensite has three times higher hardness. Here, we tried to better understand this by in-situ TEM studies. Based on the TEM studies, martensite needed higher field strength to move the domain walls than pearlite-ferrite agreeing with the BN measurement peak position. One reason for this is high dislocation density in the martensitic structure. There were strong pinning sites also in pearlite such as cementite lamellae. Even if the microstructures of martensite and pearlite are different, they have similar structural units: martensite lath / pearlite lamella, martensite packet / pearlite colony, and prior austenite grains in both. Their boundaries, wherein a crystallographic orientation changes, were observed as strong pinning sites. In martensite, both domains perpendicular and parallel to martensite laths started to move with the same field strength value. In the pearlite sample, the walls perpendicular to ferrite and cementite lamellae started to move before than the parallel walls. Our study indicates that it is very important that BN utilizers know the microstructure that they are measuring.