Final Report for ES363, The magnetic state of iron at high pressure

We investigated the magnetism of body centered cubic (bcc) FeNi alloys ($Fe_{92}Ni_{08}$, $Fe_{87}Ni_{13}$, and $Fe_{84}Ni_{16}$) as a function of pressure at room temperature through the bcc to hexagonal closed packed (hcp) phase transition. In each case, the fully saturated magnetic remanence attained maxima, 3-6 times higher than the initial value, at the hysteretic bcc→hcp and hcp→bcc transition boundaries upon compression and decompression. Magnetization maxima generally shifted to lower pressures with increasing Ni, concurrent with the phase transition. In $Fe_{84}Ni_{16}$, X-ray magnetic circular dichroism (XMCD) at the K-edge of Fe measured in a 2.5 T field together with X-ray absorption spectroscopy indicate that the magnetism defined by XMCD divided by the proportion of bcc also attains a maximum in the transition regions, similar to the magnetic remanence measurements. Enhanced remanence is attributed to a lattice mismatch between bcc and hcp Fe phases together with defect-riddled martensite. This mechanism also explains why the remanence of bcc FeNi is 2-4 times stronger at full decompression than initially, which bears on the interpretation of paleointensity records of meteorites containing bcc FeNi alloys (kamacite). Only techniques that probe magnetic states carried out in fully saturating external fields detect magnetic signals in bcc Fe residing in the hcp stability region, thereby explaining the discrepancy among the experimental results. How far in pressure bcc-Fe persists into the hcp stability field, especially at elevated temperatures, remains open.

Our results from beamline ID12 proved crucial to understand differences among the experimental techniques and show how the lattice mismatch at the phase transition gives rise to enhanced magnetism. The results were published in: Wei, Q.G., S.A. Gilder, W. Ertel-Ingrisch, F. Guillou, and F. Wilhelm (2020), Magnetism of body centered cubic Fe-Ni alloys under pressure: Strain-enhanced ferromagnetism at the phase transitions, Journal of Geophysical Research, 125, e2020JB020922, doi:10.1029/2020JB020922. ESRF Grant # ES-363 is acknowledged.