Week 15: Ferromagnetism
Announcements

Magnetic Domains

- Experimental results show that freshly smelted (solidified) iron below the Curie Temperature does not act like a magnet

Magnetic Domains

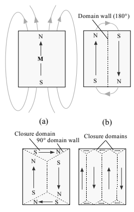

Fig. 8.22: (a) Magnetized bar of ferromagnet in which there is only one domain and hence an external magnetic field. (b) Formation of two domains with opposite magnetizations reduces the external field. There are, however, field lines at

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Why do domains form?

- If the material is magnetized, there will be magnetic field lines in the surrounding area. These field lines, just like and electric field, represent a potential energy (magnetostatic energy)

- There are easy directions: those most likely for the atoms in the domain to align to

Easy and Hard Directions

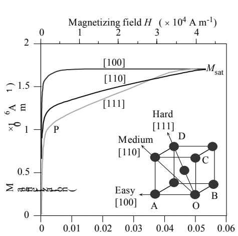

Fig. 8.24: Magnetocrystalline anisotrpy in a single iron crystal. M vs. H depends on the crystal direction and is easiest along [100] and hardest along [111]

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Domains Grow in an Applied Field

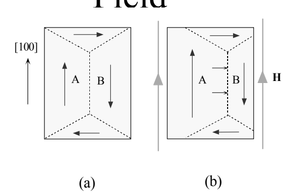

Fig. 8.23: (a) An unmagnetized crystal of iron in the absence of an applied magnetic field. Domains A and B are the same size and have opposite magnetizations. (b) When an external magnetic field is applied he domain wall migrates into domain B which enlarges A and B. The result is that the specimen now aqcuires net magnetization.

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Why don't domains keep sub-dividing?

Atoms Must Misalign at the Domain Walls

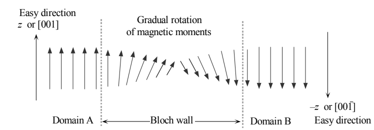

Fig. 8.25: In a Bloch wall the neighboring spin magnetic moments rotate gradually and it takes several hunbdred atomic spacings to rotate the magnetic moment by 180°.

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High Energy Domain Walls

- To reduce these high energy boundaries, domain walls occur over many atoms that slowly misalign to minimize the exchange force energy created.

Magnetic Domains

- Now what happens if we apply a magnetic field to our ferromagnet
- Atoms systematically align with the field
- The amount of magnetization (M) for a given applied field depends on how easy it is to align the domains in that direction for that particular material

Magnetization of Polycrystalline Material

- Polycrystalline material is
- Energy is lost in this process (mainly lost to the lattice as the domain walls are moved)
  - Because energy is lost, the process is not reversible
  - A hysteresis loop forms

Domains in a Polycrystalline Sample

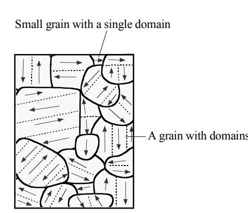

Fig. 8.29: Schematic illustration of magnetic domains in the grains of an umagnetized polycrystalline iron sample. Very small grains have single domains.

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Hysteresis of Polycrystalline Sample

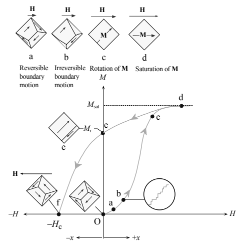

Fig. 8.30: M vs. H behavior of a previously unmagnetized polycrystalline iron specimen. An example grain in the unmagnetized specimen is that at O. (a) Under very small fields the domain boundary motion is reversible. (b) The boundary motions are irreversible and occur in sudden jerks. (c) Nearly all the grains are single domains with saturation magnetizations in the easy directions. (d) Magnetizations in individual grains have to be rotated to align with the field, H. (e) When the field is removed the specimen returns along d to e. (f) To demagnetize the specimen we have to apply a magnetizing field of Hc in the reverse direction.

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Hysteresis Loop

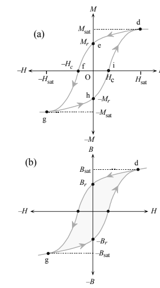

Fig. 8.31: (a) A typical M vs. H hysterisis curve (b) The corresponding B vs. H hyterisis curve. The shaded area inside the hyterisis loop is the energy loss per unit volume per cycle.

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Hysteresis Loops

- Increase magnetization
  - Atoms align to applied magnetic field
  - Magnetization increases from 0 to saturation (M_{sat})
- If magnetic field is removed, there is a ____________ left in the material
- _____________ is the magnetic field in the opposite direction required to remove this magnetic material
  - This however isn't how to demagnetize the material
  - If you remove the applied field, the magnetization in the material will got to some non-zero value
  - To demagnetize, keep cycling through smaller and smaller hysteresis cycles

Demagnetization

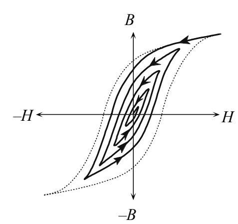

Fig. 8.34: A magnetized specimen can be demagnetized by cycling the field intensity with a decreasing magnitude, i.e. tracing out smaller and smaller B-H loops until the origin is reached, $H = 0$.

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