Magnetic properties of stainless steels

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SUMMARY

1. How an electro-valve functions
2. Magnetism and ferromagnetism: physical principles
3. Steel microstructure and ferromagnetism
4. Magnetic stainless steels - Chemical analysis
5. Manufacturing process
6. Conclusion
WHERE ARE ELECTRO-VALVES USED?

CHEMICALS, PETROCHEMICALS

HYDRAULICS valves, transmission of fluids, etc.

HOUSEHOLD APPLIANCES

FOOD DISTRIBUTION coffee machines, beverage machines, etc.

REFRIGERATION
Inlet pipe

- creation of a field strongly amplified by the inductor (fixed core)
- the mobile core moves to find an equilibrium position

• Transient phase, eddy currents occur in the magnetic components with negative actions heating (Joule effect) opposed to the initial field (Lenz's law)
  → electrical resistivity must be increased

An electrovalve is a valve (faucet) electrically controlled with electromagnetic activation
• An iron monocrystal: no spontaneous natural magnetization:
• Why? → Division into magnetic domains

B: induction

distribution of magnetic domains
HYSTERESIS LOOP

Induction $B$ vs. magnetic excitation $H$

1: demagnetized state
2: the well "oriented" domain grows to the detriment of the others
3: this process continues
4: a single domain
5: rotation of the moments
6: rotation of the moments
7: formation of new domains
8: $H=0 \rightarrow B'=0=Br$
9: $H=H_c \rightarrow B=0$

$B_s$

$H_c$

$H$

$Br$

direction of $H$

magnetic excitation $H$
THE HYSTERESIS CYCLE

- $B_r$
- $W_{hyst}$
- $H_c$
- $\mu_0 \mu_r$
RELATIONSHIP BETWEEN MICROSTRUCTURE AND MAGNETISM

Microstructural defects as grain boundaries, precipitates and dislocations are obstacles to the movement of magnetic domain walls.

1. Softening and recrystallization
2. Grain size
3. Mechanical deformation, internal stresses
Influence of softening and recrystallization

Softening kinetic followed by hardness / coercive force

Deformed state
Hc = 500 A/m

Recovered state
Hc = 300 A/m

ReX complete
Hc = 120 A/m

Annealing treatment:
- New grains (recrystallization)
- Grain growth
- Reduced straightening
- Avoid oxidization (N2, H2, vac.)

Nucleation and growth of ReX « phase »
Hc = 200 A/m
Influence of grain size on magnetic properties

Coercive field (Oe) vs. 1/grain size (mm⁻¹)
Influence of cold working

Deformed State

Annealed State

$H_c$  $\mu_{\text{max}}$
Main properties of ferromagnetic stainless steels

- **Hard ferrites**
- **Soft ferrites**
- **Al Ni Co**
- **Fe-Ni**
- **Fe-Si**
- **T-R Magnets**
- **Soft Fe-Co**

**Saturation Induction (T)**

**Coercive Force (A/m)**

- $10^6$
- $10^5$
- $10^4$
- $10^3$
- $10^2$
- $10^1$
- $10$
- $1$
- $0.1$
- $0$
Various stainless steels for magnetism

- **Corrosion Resistance**

- **Ultimate Tensile Strength (MPa)**
  - 250
  - 500
  - 750
  - 1000
  - 1250
  - 1500

- **Stainless Steels**
  - Austenitic FeCrNi
  - Ferritic FeCr
  - Martensitic FeCrC
  - Duplex

- **Annealed**
- **Hardened + Tempered**

- **Types**: para, ferro
Saturation Induction
Cr, Mo, Si : \( B_s \)

- pure iron : \( B_s \approx 2.1T \)
- with 12%Cr : \( B_s \approx 1.7T \)
- with 17%Cr : \( B_s \approx 1.6T \)

Magnetism is only due to iron atoms
- \( B_s \) decreases when %Cr or % alloying elements increases
Chemical Analysis

- Electrical resistivity must be increased in order to reduce the eddy currents
- By the addition of Si and Al
Ferritic stainless steel grades

Cr 17 % + C (<0,1%) + Fe

4016 /430 → 4105 /430F → 4105Si /430FR → 4106 (IMRE)

+ Nb → 4511 /430LNb → UGIPERM 12FM → 4106 (IMRE)
Example of dedicated solutions

Steel maker transformations → Machining → Annealing

Route 1

Steel maker transformations → Annealing → Machining

Route 2

Comparison:
- 700 parts measured
- same final value
- confirmed with customer test
- Full annealed solution is the best logistic and costs reduction route
Stainless steels offer a large range of magnetic and non-magnetic parts with high electric resistivity and high corrosion resistance.

- Ferritic steels for soft parts with fast polarization.
- Martensitic steels for compromise mechanical / magnetism.
- Duplex steels are somewhere between martensitic and austenitic steels with high corrosion resistance.
- It is almost always possible to modify desirable magnetic properties with a specific transformation’s route including thermal treatment.
- A good partnership between steel maker and customer is necessary.
Thank you for your attention