

CHAPTER FIVE

Magnetic Properties of Materials

Magnetism is one of the phenomena by which materials exert attractive or repulsive forces on other materials. It is the attractive or repulsive property exhibited by the magnet.

Magnetic Dipole: - A magnet consists of “North” & “South” poles. Any two opposite poles separated by a finite distance constitute a magnetic dipole.

Magnetic Dipole Moment or Magnetic Moment: - The product of the magnetic pole strength “m” and length of the magnet “2l” gives the magnetic moment. It is denoted by μ_m .

$$\mu_m = m \times 2l$$

When an Electric Current of I ampere flows through a circular wire of a one turn having an area of cross section A, then magnetic moment is

$$\mu_m = IA$$

It is expressed in Am^2 . It is a Vector quantity pointing from South to North Pole.

Magnetic Field: - The space surrounding the magnet up to which it's attractive or repulsion is felt is known as magnetic field.

Magnetic Field Strength (H): - The magnetic field strength H is the force experienced by a unit North Pole placed at a given point in magnetic field. It is expressed in Am^{-1} .

Magnetization or Intensity of Magnetization (M): - The magnetization M is defined as the magnetic moment per unit volume. It is expressed in Am^{-1} .

Magnetic Susceptibility (χ): - The magnetic susceptibility χ is defined as the ratio of the magnetization produced in a sample to the magnetic field strength.

$$\chi = \frac{M}{H} \quad \chi \text{ has no units}$$

Magnetic Flux Density: (B) – The magnetic flux density ‘B’ is defined as the number of magnetic lines of force passing through a unit area of cross section of magnetic material.

If 'Φ' is the number of magnetic lines of forces that passes through 'A' area of cross section of material then $B = \Phi/A$ It is expressed in Wb m^{-2} or Tesla

Magnetic Permeability (μ):- Magnetic permeability μ is defined as the ratio of the magnetic induction or magnetic flux density B to the applied magnetic field intensity H.

$$\mu = \frac{B}{H}$$

$$B = \mu H$$

In free space $B_0 = \mu_0 H$ where $\mu_0 = 4\pi \times 10^{-7} \text{ Hm}^{-1}$. μ_0 is the permeability of free space.

Relative Magnetic Permeability (μ_r):- It is defined as the ratio of permeability of a material to the permeability of free space.

$$\mu_r = \frac{\mu}{\mu_0}$$

$$\mu = \mu_0 \mu_r$$

Relation between B, H and M: -

$$B = \mu H$$

$$B = \mu_0 \mu_r H \quad (\because \mu = \mu_0 \mu_r)$$

$$B = \mu_0 \mu_r H + \mu_0 H - \mu_0 H$$

$$B = \mu_0 H + \mu_0 H (\mu_r - 1)$$

$$B = \mu_0 H + \mu_0 M \quad (\because M = H (\mu_r - 1))$$

$$B = \mu_0 (H + M)$$

Relation between χ and μ_r : -

$$B = \mu_0 (H+M)$$

$$\mu_0 = \frac{B}{H + M}$$

$$\mu_r = \mu/\mu_0$$

$$\mu_r = \frac{(B/H)}{B/(H+M)} \quad (\because \mu = B/H)$$

$$\mu_r = \frac{(H+M)}{H}$$

$$\mu_r = 1 + M/H$$

$$\mu_r = 1 + \chi \quad (\because \chi = \frac{M}{H})$$

Classification of Magnetic Materials: -

The matter is made of atoms, each atom has a positively charged nucleus at its center and around the nucleus negatively charged electrons revolves in various orbits, and the revolving electron behaves like a magnetic dipole, which has some magnetic moment. This magnetic moment arises due to orbital revolution is negligibly small. Hence, most of the magnetic moment is produced due to electron spin.

In general the magnetic materials can be classified as

- (i) Diamagnetic Substances
- (ii) Para magnetic Substances
- (iii) Ferro magnetic Substances.

Diamagnetism

- An electron moving around the nucleus results in magnetic moment. Due to different orientations of various orbits of an atom, the net magnetic moment is zero in diamagnetic materials.

When an external magnetic field is applied the motion of electrons in their orbits changes resulting in induced magnetic moment in a direction opposite to the direction of applied field. Thus diamagnetism is property of all atoms because of the influence of an applied magnetic field on the motion of electrons in their orbits.

Properties of Diamagnetic Materials: -

- (1) Permanent dipoles are absent i.e. magnetic moment in each atom is zero.
- (2) Susceptibility χ is negative for these materials and is independent of temperature and strength of applied magnetic field.
- (3) No spin alignment is present
- (4) In the presence of magnetic field, the magnetic lines of force are pulled out from the material,

In the case of perfect diamagnetic material like low temperature super conductor, the diamagnetic property disappears if the temperature is increased above the superconducting transition temperature than it behaves like a normal material.

- (5) Relative permeability $\mu_r < 1$
- (6) Examples. Organic materials. Bi, Zn, H₂O, Gold etc

Para magnetism

- (1) Each electron in an orbit has an orbital magnetic moment and a spin magnetic moment.
- (2) When shells are unfilled there is a net magnetic moment.
- (3) In the absence of external magnetic field the net moments of the atoms are arranged in random directions. Hence there is no magnetization.
- (4) When external magnetic field is applied there is tendency for the dipoles to align with the field gives rise to an +ve dipole moment. This induced dipole moment is proportional to the field. The induced magnetism is the source of Para magnetism.

Properties of Paramagnetic Materials: -

- (1) Paramagnetic materials possess permanent magnetic dipoles.
- (2) Susceptibility χ is positive and small for these materials.

Susceptibility is inversely proportional to the temperature T i.e. $\chi \propto \frac{1}{T}$

$\chi = \frac{C}{T}$ where C is curie's constant.

(3) In the presence of magnetic field, the magnetic lines of the force are attracted forwards the centre of the material.

(4) Below superconducting transition temperature, the paramagnetic materials exhibit diamagnetism.

(5) Relative permeability $\mu_r > 1$

(6) Examples; : Al, Pt, Mn, CuCl_2 , Alkali metals & Transition metals

Ferro Magnetism

Classification of Ferromagnetic Materials: -

Depending upon the spin orientation of the electrons, ferromagnetic materials are classified into two types, they are

- i) Anti-ferromagnetic materials
- ii) Ferromagnetic materials.

Properties of Anti Ferromagnetic Materials: -

- Susceptibility is small and positive.
- The temperature at which anti ferromagnetic material converts into paramagnetic material is known as Neel's temperature.
- Susceptibility is inversely proportional to the temperature the variation of susceptibility with temperature

$$\chi = \frac{C}{T + \theta} \text{ when } T > T_N \text{ (Neel's temp)}$$

(2) Relative permeability $\mu_r > 1$

(2) Examples : Oxides of Ni, Cr, Fe, etc

(NiO, FeO, MnO, Cr_2O_3)

Properties of Ferromagnetic Materials: -

- Ferromagnetic materials possess permanent dipole moment or magnetic moment in each atom. The induced magnetic moment produced by the external magnetic field is very large and it increases the magnetic induction present in the materials.
- Susceptibility is always positive and large and it depends upon temperature in a complex manner. This behavior shown in fig.

$$\chi = \frac{C}{T - \theta} (T > \theta)$$

Where 'θ' is Curie temperature

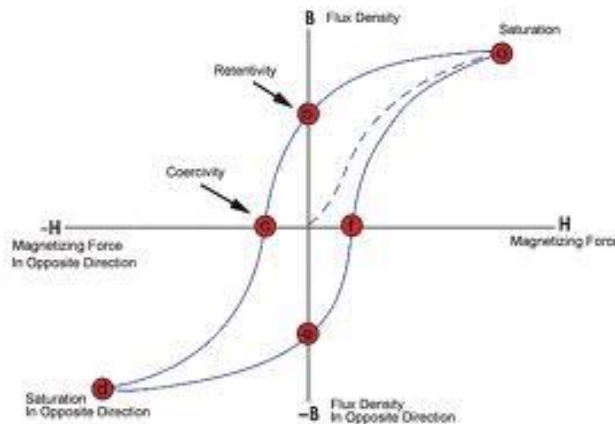
- In the presence of the magnetic field, the magnetic lines of forces are highly attracted towards the center of the material and hence, the magnetic field induction inside the material is very greater than the outside
- When the temperature of material is greater than its Curie temperature, it converts to paramagnetic material.
- The relative permeability $\mu_r \gg 1$

Ferrites are the best examples for ferromagnetic materials.

Examples: ZnFe_2O_4 , CuFe_2O_4 , $\text{Zn} - \text{CuFe}_2\text{O}_4$, $\text{Ni} - \text{CdFe}_2\text{O}_4$ etc

Hysteresis Curve

1. Hysteresis means lagging of an effect behind the cause of the effect. In magnetism, hysteresis has been used between the applied magnetic field strength 'H' and Magnetic flux density 'B'. The variation in B with variation in H is shown in Fig.



2. The point 'O' represents an initially unmagnetized specimen and a zero magnetic intensity. As H is increased, B also increases but not uniformly and a point 'a' is reached.

3. If H is decreased, B also decreases but following a path 'ab'. Thus B lags behind H when H becomes zero. B still has a value equal to 'ob'
4. The magnetic flux density remaining in the specimen in the absence of any external field is called the 'residual magnetism'
5. The power of retaining this magnetism is called the 'retentivity' or remanence (B_r) of the specimen.
6. If the magnetic intensity H is now increased in the reverse direction the value of the B further decreases still lagging behind H, and becomes zero, and H has a value equal to OC. This value of the magnetic intensity is called the coercive force or coercivity of the specimen.
7. The coercivity H_c is a measure of the magnetic intensity required to destroy the residual magnetism of the specimen.
8. H is increased beyond OC the specimen is increasingly magnetized in the opposite direction and a point 'd' is reached.
9. By taking H back from its negative maximum value, through zero, to its original positive maximum value, a similar curve is obtained.
10. At points 'b' and 'e' where the specimen is magnetized in the absence of any external magnetic intensity, it is said to be a permanent magnet.
11. The closed curve 'abcdefa' which represents a cycle of magnetism of the specimen is known as the Hysteresis loop

Hard and Soft Magnetic Materials

Depending upon the size of the hysteresis loop the magnetic materials are classified into two types.

Soft magnetic materials: - The materials which are easily magnetized and demagnetized are said to be soft magnetic materials.

The soft magnetic materials are prepared by heating the pure material to a temperature at which sufficient movement of the atoms is possible for them to settle into an ordered lattice, followed by slow cooling.

Properties:

- (1) The nature of the hysteresis loop of a soft magnetic material is very steep.
- (2) The hysteresis area is very small and hence the hysteresis loss is also small.
- (3) These materials have large values of susceptibility and permeability.
- (4) The coercivity and retentivity values are small.
- (5) These materials are free from irregularities like strain (or) impurities.

Examples: (1) Iron – Silicon alloys (2) Nickel – Iron alloys
(3) Iron – Cobalt alloys.

Hard Magnetic Materials

The materials which are very difficult to magnetize and demagnetize are said to be hard magnetic materials.

The hard magnetic materials are prepared by heating the magnetic materials to the required temperature and then suddenly cooling them by dipping in a cold liquid.

Properties:

- (1) The nature of the hysteresis curve is very broad and has a large area.
- (2) The hysteresis loss is very large
- (3) These materials have low value of susceptibility and permeability.
- (4) The coercivity and retentivity values are large
- (5) These materials have large amount of impurities and lattice defects.

Examples: Carbon Steels, Tungsten Steel, Chromium Steel, Alnico etc.

Chromium Steel is the best permanent magnet.