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MATERIAL SCIENCE

BRANCH :- MECHANICAL ENGINEERING

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Unit 5 – Topic 3: Annealing and Its Types

1. Introduction to Annealing

Annealing is a heat treatment process in which a metal is heated to a specific temperature, held there for some time, and then cooled slowly, usually in a furnace.

It is mainly used to:

- Soften the material
- Relieve internal stresses
- Improve ductility
- Refine grain structure
- Improve machinability

2. Purpose of Annealing

Purpose	Explanation
• Reduce hardness or shape	Makes the material easier to cut, machine,
• Increase ductility formed without cracking	Allows the material to be drawn or
• Relieve internal stresses	Stresses developed during welding,
• Refine grain structure	casting, or cold working are reduced
• Improve machinability and formability	Improves mechanical properties and
	toughness
	Makes materials more

suitable for industrial operations

- **Restore original properties** **After cold working or strain hardening**

3. General Annealing Process

- Heating the metal to a predetermined temperature

(Usually 30–50°C above its upper critical temperature for steels)

- Holding the material at that temperature for a sufficient period

(This allows changes in the internal structure)

- Slow cooling in the furnace or under controlled conditions

(This ensures the formation of soft and stable microstructures)

4. Types of Annealing

There are several types of annealing processes, each with a different goal and temperature cycle:

1. Full Annealing

- **Purpose:** To achieve maximum softness and ductility
- **Temperature:** Heated to about 30–50°C above A_3 (for hypo-eutectoid steels)
- **Cooling:** Very slow cooling in the furnace
- **Microstructure obtained:** Coarse ferrite + pearlite
- **Used for:** Low-carbon steels before machining or forming.

2. Process Annealing

- **Purpose:** To relieve internal stresses from cold working
- **Temperature:** Around 550–650°C (below lower critical temp)
- **Cooling:** Usually in air
- **Does not affect grain structure significantly**
- **Used for:** Mild steels in manufacturing (sheet metals, wires, rivets)

3. Spheroidizing Annealing

Purpose: To convert cementite into spherical particles

Temperature: Just below eutectoid temperature (723°C) for long duration

Cooling: Very slow

- **Produces softest possible structure in high-carbon steels**
- **Microstructure: Spheroidized cementite in ferrite matrix**
- **Used for: High-carbon tool steels (for better machinability before hardening)**

4. Stress Relief Annealing

Purpose: To remove internal stresses without changing mechanical properties

Temperature: 400–650°C

Cooling: Controlled (in furnace)

- **Does not alter microstructure significantly**
- **Used after welding, casting, machining, forging**

5. Diffusion Annealing (Homogenizing)

Purpose: To eliminate chemical composition differences (segregation)

Temperature: Very high (1100–1200°C)

Holding Time: Long (up to 10–20 hours)

Cooling: Slow cooling

Used for: Ingot or cast materials to remove chemical inhomogeneity

6. Isothermal Annealing

Purpose: To get a uniform structure and better control over grain size

- **Method:**
 - **Heat above critical temp**
 - **Rapidly cool to a temp just below critical point**
 - **Hold till transformation is complete**
- **Cooling:** Air or furnace
- **Useful in controlled industrial processes for better mechanical properties.**

5. Comparison of Annealing Types

Type	Temp. Range	Purpose	Cooling Used For
• Full Annealing	800–950°C	Softening, ductility	Slow in furnace Low-carbon steels
• Process Annealing	550–650°C	Relieve stress from cold work	Air Mild steel sheets, wires
• Spheroidizing	~720°C	Make cementite round, easy machining	Very slow Tool steels, high-carbon steels
• Stress Relief	400–650°C	Remove internal stress	Controlled After welding or machining
• Diffusion Annealing	1100–1200°C	Remove chemical segregation	Very slow Ingots and large castings
• Isothermal Annealing	Varies	Uniform microstructure	Air/furnace High-precision parts

6. Microstructural Changes During Annealing

Before Annealing	After Annealing
• Strained grains	Recrystallized grains
• Dislocations present	Dislocation-free structure
• Hard and brittle	Soft and ductile
• Internal stress high	Stress relieved

7. Applications of Annealing

- **Automotive industry:** To soften parts before forming or shaping.
- **Tool manufacturing:** To improve machinability of tool steels.
- **Sheet metal:** Used extensively to prepare cold-rolled sheets.
- **Welding:** To relieve stress from welded joints.

8. Advantages of Annealing

- **Improves ductility and toughness**
- **Enhances machinability**

- **Reduces risk of failure during operation**
- **Allows better dimensional control in precision parts**
- **Improves microstructure uniformity**

9. Disadvantages of Annealing

- **Time-consuming (especially full or diffusion annealing)**
- **Increases energy costs**
- **May reduce strength and hardness (in some cases)**