



# Gear heat treatment



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## ➤ Normalizing

1. Grain refinement: Eliminates the coarse microstructure after forging and homogenizes grain size.
2. Residual stress relief: Reduces residual stresses to lower the risk of distortion during subsequent machining/processing.
3. Improved machinability: Provides a suitable hardness for machining (e.g., for medium-carbon steel, a typical target is 160–200 HB).



### Key Normalizing Process Parameters (Example: 42CrMo)

Parameter	Typical Range (42CrMo Example)	Control Notes
Heating temperature	850–880 °C	Ac3 + 30–50 °C
Soaking time	1.5–2.0 min/mm (section thickness)	For box furnaces, use the upper end of the range
Cooling method	Still air	Avoid cross-drafts to prevent uneven cooling
Furnace loading / spacing	Spacing $\geq$ workpiece diameter	Prevent local overheating / insufficient cooling

- Coordination with forging: Charge into the furnace immediately after forging (interval < 2 h).
- Material effect: Higher carbon content  $\rightarrow$  lower normalizing temperature.

## Typical Normalizing Temperature by Material

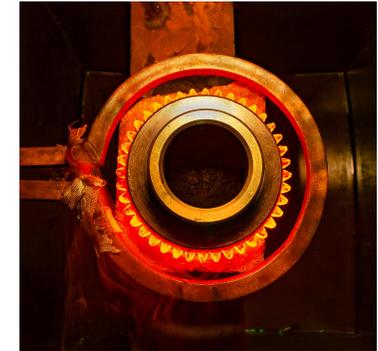
- Low-carbon steel (20Cr):890–920 °C
- Medium-carbon steel (42CrMo):850–880 °C
- High-carbon steel (GCr15):800–830 °C

## ➤ Quenching

Function / Purpose:

- Property enhancement: Increases strength, hardness, and wear resistance.

Key Quenching Process Parameters (Example: 40Cr)



Parameter	Control Notes	Typical Example (40Cr)
Austenitizing temperature	Heat above Ac3(hypoeutectoid steels) or above Ac1(hypereutectoid steels), but avoid overheating/burning	850 ± 10 °C(Ac3 ≈ 780 °C)
Soaking time	Based on effective section thickness: $t = \alpha \times D$ (for box furnace: $\alpha = 1.5 \text{ min/mm}$ )	25 mm part → 37.5 min
Quenching medium	Select per material CCT/TTT “C-curve”: water (carbon steels) / oil (alloy steels) / polymer (distortion-sensitive parts)	No. 20 quenching oil(cooling rate ≈ 80 °C/s)
Transfer time	< 5 s to prevent proeutectoid phase precipitation before quenching	Controlled via automatic quenching equipment

## Gear heat treatment

40Cr Hardness After Quenching (Oil Quench):

- Surface hardness: 52–56 HRC (can reach)
- Core hardness: 45–50 HRC

### ➤ Tempering



### Functions of Tempering (After Quenching)

- Relieve quench-induced residual stress: Quenched martensitic structures can retain very high residual stresses (reported up to ~70%); tempering can reduce residual stress by more than 80%.
- Tune mechanical properties: Controls the hardness–toughness balance through carbide precipitation. (Example: 42CrMo gear: 58 HRC (as-quenched) → 32–38 HRC (after tempering).)
- Stabilize dimensional accuracy: Reduces later distortion caused by microstructural transformations.

## Tempering Temperature Levels & Typical Effects

Item	Low-Temperature Tempering (< 250 °C)	Medium-Temperature Tempering (350–500 °C)	High-Temperature Tempering (500–650 °C)
Typical applications	High-hardness tools	Springs / bearings	Gears / shafts (quench & temper)
Hardness change	– 1–3 HRC	– 10–15 HRC	– 20–25 HRC
Soaking time	1.5–3 h	2–4 h	1.5–2 h

Higher tempering temperature → larger hardness reduction.

### Typical Production Route (General)

Forging → Normalizing → Machining → Quenching → Tempering → Grinding / Finishing

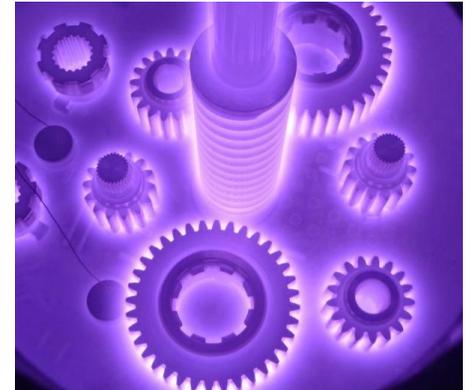
## ➤ Nitriding

Nitriding is a surface heat treatment process that introduces nitrogen atoms into the metal surface to form a hard nitride layer, significantly improving surface hardness, wear resistance, and corrosion resistance, thereby enhancing overall component performance.

### 1. Nitriding Process Types

#### 1) Gas Nitriding

- Process: Ammonia ( $\text{NH}_3$ ) is introduced into a sealed furnace; it dissociates to generate active nitrogen for diffusion into the surface.
- Pros: Precise controllability; suitable for complex-shaped parts.
- Cons: Long cycle time (often tens of hours); higher cost.



### 2) Plasma Nitriding (Ion Nitriding)

- Process: In a vacuum furnace, a high-voltage electric field ionizes an  $N_2 / H_2$  gas mixture to form a plasma that activates/impacts the surface.
- Pros: Fast (typically hours), low distortion, more environment-friendly (lower gas consumption).
- Cons: Complex equipment; requires tight parameter control.

### 3) Salt Bath Nitriding (Liquid Nitriding)

- Process: Nitriding in a cyanate-based salt bath; now used less frequently due to environmental concerns.
- Note: In external-facing materials, avoid over-detailing chemistry; keep compliance wording clear.

### 4) Low-Temperature Nitriding

- Purpose: For stainless steels and similar materials, performed below  $\sim 400$  °C to avoid chromium carbide precipitation and preserve corrosion resistance.

## 2. Suitable Materials for Nitriding

- ① Nitriding steels: Contain Cr, Mo, V, Al (e.g., 38CrMoAl), which readily form stable nitrides.
- ② Tool steels: Such as H13 and D2 to extend die/mold service life.
- ③ Stainless steels: Austenitic stainless steels (e.g., 304) can be nitrided to increase surface hardness.
- ④ Cast iron: Improves wear resistance for parts such as cylinder liners and crankshafts.

Hardness values of different materials after nitriding

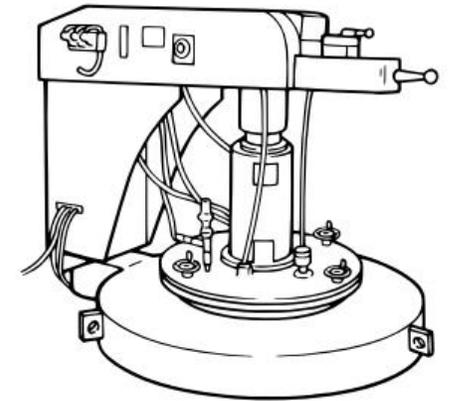
Material Type	Surface Hardness (HV)	Effective Case Depth
Quenched & tempered steel (42CrMo)	650–800 HV	0.3–0.6 mm
Dedicated nitriding steel (38CrMoAl)	800–1100 HV	0.4–0.8 mm
Stainless steel (17-4PH, 316)	900–1300 HV	0.2–0.5 mm

## ➤ Carburizing

Carburizing is a thermochemical surface treatment that diffuses carbon into the surface of low/medium-carbon steel. After quenching and low-temperature tempering, it delivers high surface hardness and wear resistance while keeping the core tough and strong.

### 1. Gas Carburizing

- Medium: Hydrocarbon atmospheres (e.g.,  $\text{CH}_4$  ,  $\text{C}_3\text{H}_8$  ) or natural gas mixed with a carrier gas (e.g., endothermic gas).
- Key points: High control accuracy, suitable for mass production; manage carbide/carbide-network risk.
- Typical temperature:900–950 °C



### 2. Solid (Pack) Carburizing

- Medium:Charcoal + carbonate activators (e.g.,  $\text{BaCO}_3$  ) (as an activator).
- Key points: Simple equipment; lower efficiency and poorer environmental profile; used for small batches or repair parts.
- Typical temperature:850–950 °C

### 3. Liquid Carburizing (Salt Bath Carburizing)

- Medium:Cyanide-based or cyanide-free salt baths (industrial, regulated).
- Key points:Fast (often 1–4 h); high toxicity/strict safety & compliance requirements for certain baths.
- Typical temperature:850–930 °C

### 4. Vacuum / Low-Pressure Carburizing (LPC)

- Medium: Hydrocarbon gases (e.g.,  $C_2H_2$ ) decomposed under low pressure.
- Key points: Low oxidation, low distortion; suitable for precision parts; cleaner and efficient.

### 5. Plasma (Ion) Carburizing

- Mechanism: Carbon ions are driven into the surface by glow-discharge plasma.
- Key points: High efficiency and energy-saving potential; higher equipment cost.

### Suitable Materials for Carburizing

- Low-carbon steels (e.g., 20 steel, 20Cr): cost-effective and respond well to carburizing.
- Low-carbon alloy steels (e.g., 20CrMnTi, 20CrMo): alloying elements (such as Cr, Ni, Mo) improve hardenability, making them suitable for high-load components.
- Cast iron: Certain ductile (nodular) cast irons can also be carburized.

Process Flow: Carburizing → Quenching → Low-Temperature Tempering

### ➤ **Carbonitriding**

Carbonitriding is a thermochemical surface treatment that diffuses carbon (C) and nitrogen (N) into the surface, creating a hardened case with improved hardness, wear resistance, and fatigue strength—combining key benefits of carburizing and nitriding.

#### **1. Suitable Materials for Carbonitriding**

- Low-carbon steels (e.g., 20, 20Cr): cost-effective and achieve good surface strengthening after carbonitriding.
- Low-carbon alloy steels (e.g., 20CrMnTi, 20CrMo): alloying elements (e.g., Cr, Mo) improve hardenability.
- Medium-carbon steels (e.g., 45 steel): suitable for parts requiring higher core strength.

## 2. Carbonitriding Types

- Gas Carbonitriding
- Liquid Carbonitriding (Salt Bath Process)
- Vacuum Carbonitriding

**Process Flow:** Carbonitriding →  
Quenching → Low-Temperature Tempering

### Carbonitriding vs. Carburizing vs. Nitriding (Quick Comparison)

Comparison Item	Carbonitriding	Carburizing
Process temperature	750–880 °C	850–950 °C
Effective case depth	0.2–1.0 mm	0.3–2.0 mm
Surface hardness	58–65 HRC	58–64 HRC
Distortion	Low(typically lower than carburizing)	Higher
Corrosion resistance	Relatively good(often better than carburizing)	Moderate
Typical materials	Low-carbon steels, alloy steels	Low-carbon steels, alloy steels

## ➤ High-Frequency Induction Hardening

High-Frequency Induction Hardening is a localized surface heat treatment that uses electromagnetic induction to rapidly heat the surface and then quench it, producing high surface hardness with controlled case depth and low distortion while keeping a tough core.

### 1. Increase Surface Hardness & Wear Resistance

- Rapid heating austenitizes the surface layer, followed by quenching to form high-hardness martensite. The surface hardness can reach 50–58 HRC (depending on the material).

### 2. Maintain Core Toughness

- Only the surface is hardened (typical case depth 1–5 mm), while the core retains its original microstructure (e.g., ferrite + pearlite), helping avoid overall brittleness.

### 3. Low Distortion, High Dimensional Accuracy

- Localized heating and rapid quenching create a narrow heat-affected zone (HAZ), resulting in minimal distortion—well suited for precision parts (e.g., machine-tool lead screws/ballscrews).



**Process Flow:** Pre-treatment (Quench & Temper / Q&T) → High-Frequency Induction Heating → Quenching (Cooling) → Low-Temperature Tempering

### **Best-suited materials:**

- Medium-carbon steels (e.g., 45 steel, 50 steel)
- Alloy steels (e.g., 40Cr, 42CrMo)
- Cast iron (e.g., ductile/nodular cast iron)

### **Less suitable materials:**

- Low-carbon steels(limited hardness increase)
- High-carbon steels(higher cracking risk)

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