Cast Iron (CI):

- **Types of Cast Iron:**
  - White CI (all C combined Fe_3C.
  - Malleable CI (most C uncombined).
  - Gray CI (most C uncombined in form of Graphite flakes).
  - Chilled CI (White CI layer at surface + Gray Iron interior).
  - Nodular CI (the C uncombined in the form of compact spheroids)
  - Alloy CI.

Cast Iron (CI):

➢ White CI:

- Hard + Wear resistance + Brittle

- They are used where resistance to wear is most important and the service does not require ductility (ex. Liner for Cement mixer, ball mills, drawing dies).

- White CI ⟶ Malleable CI.

- Mechanical Properties ⟶ H_B (375 – 600).

  T. S (20,000 – 70,000) psi.

  C. S (200,000 – 250,000) psi.

  E (24 – 28) X 10^6 psi.

➢ Malleable CI:

- Fe_3C (Metastable Phase) at:

  1- Elevated Temperature.

  2- Existence of solid non metallic impurities.

  3- Higher C content.

  4- Presence of element that cause decomposition of Fe_3C.

$$Fe_3C \rightleftharpoons 3\,Fe + C$$

Cast Iron (CI):

➢ Malleable CI:

- The purpose of malleabilization is to convert all **Fe_3C** in (**white CI**) ⟶ irregular (nodules of graphite + Ferrite) by two stages of annealing:

1st stage - white CI $\xrightarrow[\text{(1650 -1750)oF}]{\text{Slowly reheated}}$ Pearlite **P** ⟶ γ ⟶ dissolve **Fe_3C** as it is heated to annealing Temperature **T°**.

Fe_3C $\rightleftarrows$ **3 Fe + C** ⟶ graphitization starts at malleabilizing Temperature T.

- ❖ ترسيب نوى الكرافيت يستنزف كاربون السمنتايت.
- ❖ تحلل السمنتايت يستمر ويؤدي بدوره إلى ترسيب (C) أكثر على نوى الكرافيت.
- ❖ تنمو نوى الكرافيت بمعدلات متساوية في كل الإتجاهات وبالنهاية تظهر **(nodules)** عقد أو ما يشبه الكرات تسمى **(Temper C)** أو **(Temper Graphite)** يتكون على السطح البيني بين الكاربيد الإبتدائي والأوستنايت المشبع خلال **(1st stage annealing)** وينمو حول النوى أثناء التفاعل الذي يتضمن تداخل وتحلل الكاربيد.....

Cast Iron (CI):

➢ Malleable CI:

- Nucleation + graphitization accelerated by the presence of (**Si** & **C**) and it will be increased (↑).

- The rate of annealing depend on
  → Chemical composition.
  → Nucleation tendency.
  → T^o of annealing α (no. of temper **C** particles produced).

- **T^o** of annealing ↑ → ↑ more graphite particle / unit area.

- Annealing Temperature controlled between 1650 1750 ^{o}F.

- Held at this temperature until all massive Carbide have been decomposed (30 – 72) hour.

- The surface of 1st stage (temper Carbon nodules distributed in matrix of Austenite γ.

Cast Iron (CI):

➢ Malleable CI:

2nd stage – (see fig. 24).

- Cooled slowly at rate of 5 – 15 ºf / hr.
- **C** (dissolved in γ) ⟶ graphite.
- Reheating γ ⟶ α .

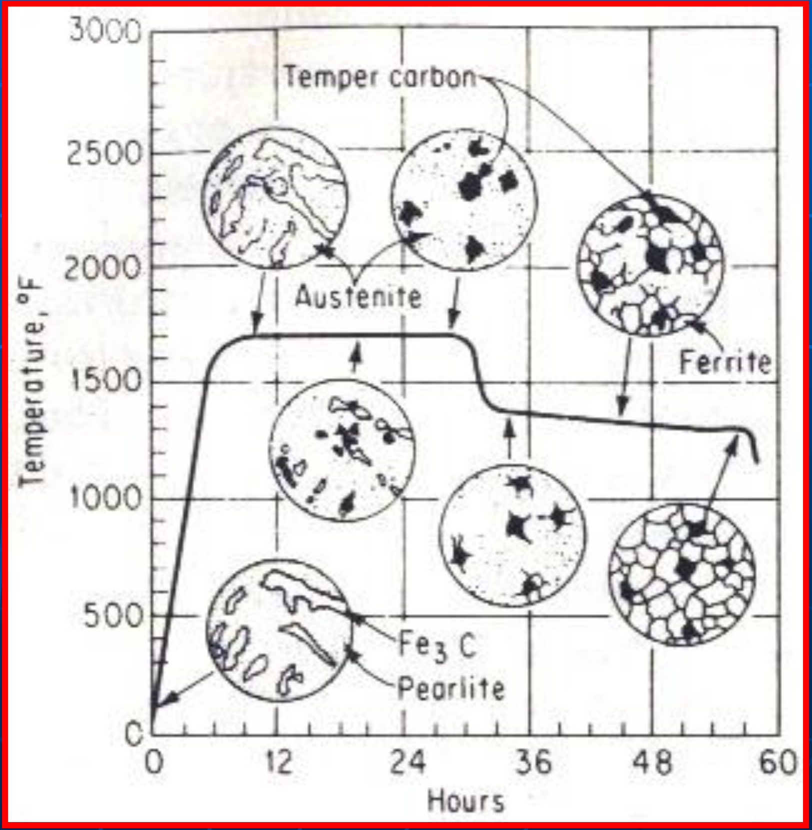

Fig. (24), The change in microstructure as a function of malleabilizing Cycle.

Cast Iron (CI):

➢ Gray CI:

- Gray CI are hypoeutectic alloy (2.5 – 4)% C.

- Strength of Gray CI depend on the matrix in which the graphite is embedded.

If matrix is α ⟶ Ferritic Gray CI (soft + weak).

If matrix is P ⟶ Perritic Gray CI.

If matrix is (α + P) ⟶ Ferritic & Perritic Gray CI.

- Si ⟶ increase fluidity of molten alloy + shift the eutectic composition to the left, it is a graphitizer.

- The highest tensile strength is obtained with (2.75% C + 1.5% Si) ⟶ over 40,000 psi (see fig. 25).

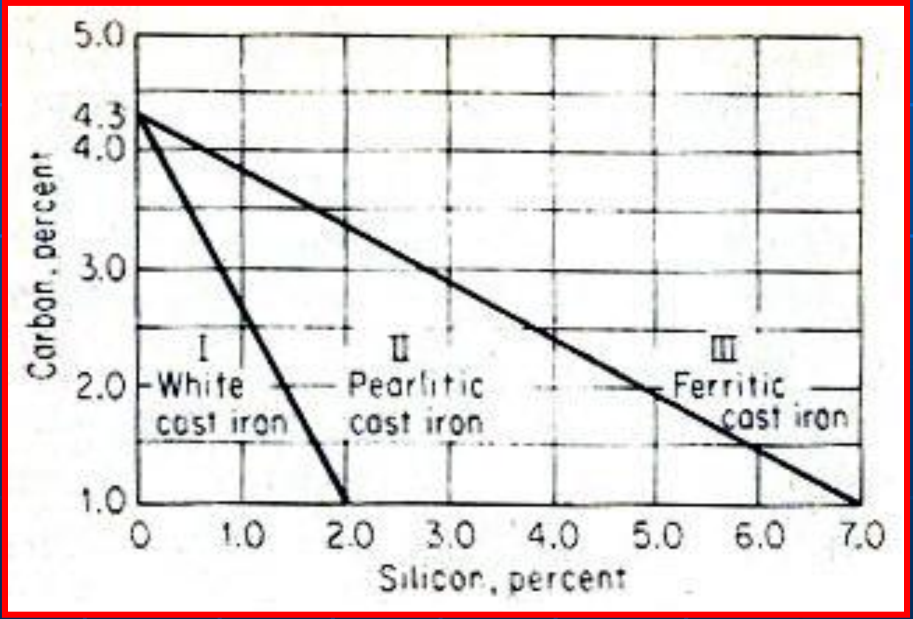

Fig. (25), Relation of Structure to C & Si content of CI.

Cast Iron (CI):

➢ Gray CI:

- **S** is present in commercial **Gray CI** between (0.06 – 0.12)%, the effect of **S** is opposite to the effect of **Si**.

Fe + S ⟶ **FeS** (lower the melting point ↑ + increase cracking at elevating Temperature T^o ↓).

- **Mn** Carbide stabilizer, increase the amount of combined **C**.

Mn + S ⟶ **MnS**

- **P** is present in **Gray CI** between (0.1 – 0.9)% ⟶

P + 3Fe ⟶ **Fe_3P.**

Fe_3P + Fe_3C + γ ⟶ Ternary eutectic (**Steadite**) ⟶ Brittle ⟶ High P 10.2% ⟶ Melting T^o (1920 ^{o}F)

- **P** increases the fluidity.

❖ إذا أمكن السيطرة على محتويات (**S, Mn, Si, P**) فأن مقاومة **Gray CI** يمكن التحكم بها من خلال **(Graphite Flakes)** حجمها وشكلها و توزيعها.

Heat Treatment of Gray Iron:

1. Stress Relief:

- Residual stress in CI (Gray I) causes → Reduce strength → Distortion → Cracking
- T° of stress relieving is (1000 – 1050)°f (below the transformation of range P → γ).
- Holding 1 hr at this range (75 – 85)% of residual stress can be removed. (see fig. 26)

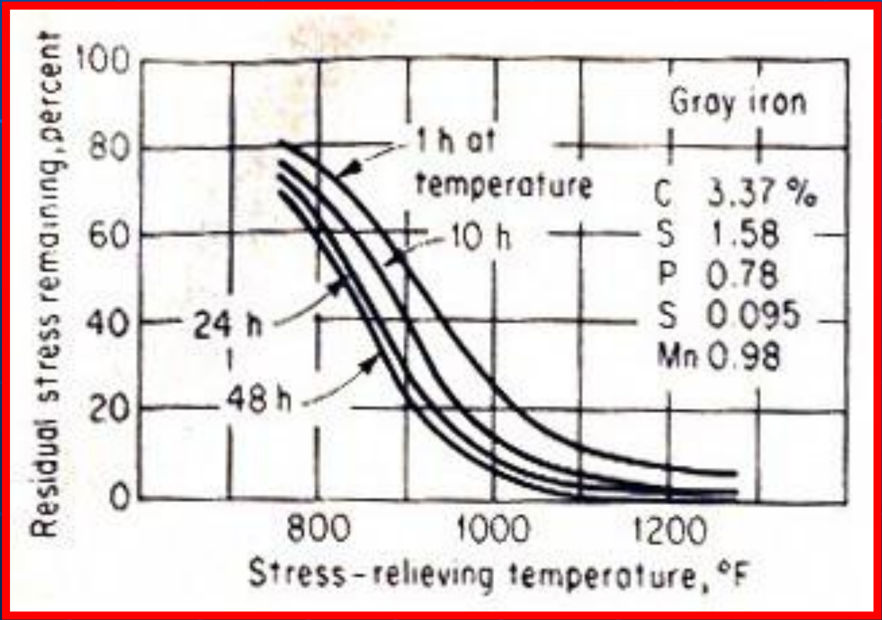

Fig. (26), Effect of Time & Temp. on Residual Stress

Heat Treatment of Gray Iron:

2. Annealing:

- Heating to T° (1300 – 1400) °f:

$$Fe_3C \longrightarrow \alpha + C$$

- Holding at this T° for along time to allow the graphitizing process completion.

3. Normalizing:

- Heating to T° (1625 – 1700) °f

$$Fe_3C \longrightarrow \alpha + C$$

- Holding at this T° for 1 hr/in of max. section thickness.
- Cooled in still air to R_T°.

Heat Treatment of Gray Iron:

4. Hardening:

- Gray Iron like steel can be hardened when cooled rapidly (Quench).
- Gray Iron is furnace hardened from (1575 – 1600) ºf, then reheating in the range from (300 – 1200) ºf → Increase toughness + Stress relief.
- Quenching medium (water, oil, hot salt, air) depend on composition + section size.

Quenching medium → Water → Used for quenching with flame or induction hardening

Water → Very drastic → cause cracking + distortion unless the casting are → massive / uniform cross section

Quenching medium → Hot Oil or Hot Salt → minimize (Distortion + Quenching Cracking)

Cast Iron (CI):

➢ Nodular Cast Iron: (Ductile Iron, Spheroidal Graphite)

❖ CI in the graphite is present as tiny balls or spheroids because of the presence of alloying element (Mn, Ce, S < 0.015) ⟶ this alloys described as (Desulfurized).

❖ Strength + Toughness > Gray Iron that is obtained as a solidification & doesn't need heat treatment (H. T).

C% (Gray) = C% (Nodules)

❖ ***Types of Nodular CI:***

Ferritic

(P) In matrix <10%

Pearlitic

(p) In matrix > 10% normalized by air cooling from (1600 – 1650) ºf

↓

Stronger, less ductile

Quenched

Obtained by quenching in oil or water from (1600 – 1650) ºf

Austentic

(Highly alloying type)

High corrosive resistance + good Creep resistance

Heat Treatment of Nudolar Iron:

Stress Relief

Purpose:
stress relief range (1000 – 1150) ^{0}f, time 1 hr/in of section

Ferritizing anneal

- Heat to 1650 ^{o}f
- Cool to 1450 ^{o}f in 1 hr.
- Cool to 1200 ^{o}f at 35 ^{o}F/hr.

Normalize

- **Purpose**: to obtain Pearlitic structure.
- Heat to 1650 ^{o}f
- Hold at a temp.
- Cool to 1450 ^{o}f in Furnace.
- Air Quench (may be temper).

Quench & Temper

Purpose: higher Strength + hardness

- Heat to 1600 – 1650 ^{o}f.
- Oil Quench.
- Tempered.

Surface hardening

Purpose: wear resistance

1 - Flame Hardening

Hardness (C53 – C60) is obtained.

- Care should be taken to relief residual stress prior to flame hardening to get rid of cracking in hardened case + stress relief after hardening is desirable (300 – 400) ^{o}f.

2 – Induction hardening

Heat Treatment of White Iron (WCI):

Heat Treatment for refinement of structure

Heat Treatment to reduce high residual stress:

- Fairly high T° may be employed for stress relief (1500 – 1600) °f:

  - As the T° increased the time at T° must be reduced to prevent Graphitization.

- Martensitic, Ni – Cr white iron ⟶ abrasion resistance.

  - High Tempering T° ⟶ loss in abrasion resistance.

  - Tempering for 3 hr at 400 °f ⟶ stress relief without altering abrasion resistance.

Unalloyed

- Heat treated at relatively high T° (18 hr at 1500 °f or 8 hr at 1600 °f).

↓

To accomplish re-solution of coarse primary carbide.

↓

Cooling to produce fine + uniform grain structure [improve mechanical properties + small loss in hardness & wear resistance].

Martensitic (Ni – Cr)

May have large amount of retained (γ) in matrix.

↓

Undesirable, most of (γ) may be eliminated by:

- Tempering (5 hr at 800 °f) or (3 hr at 900 °f).
- Exposure to subzero T° (- 300 °f all γ ⟶ M) or (- 50 °f, 40% γ ⟶ M).

Cast Iron (CI):

- **Alloy Cast Iron:** Cast Iron + added elements (except Si, S,P which are normally obtained from raw material).

  - Alloying element (Cr, Cu, Mo, Ni, V) will accelerate or retard graphitization.

  - **Cr:** Cr + C → Combined C (more stable)

Cr increase → Strength

→ Hardness

→ Depth of chill

→ Resistance to wear + Heat

Cr decrease → machinability

Cast Iron (CI):

❖ The effect of Cr on microstructure illustrated as:

Cr%	Structure
0	α + Coarse graphite (G)
0.3	< α + less (P) + finer (G)
0.6	P (Pearlite) + fine (G)
1.0	P + fine (G) + small Carbide
3.0	Disappear of (G)
5.0	much Carbide
10 – 30	fine Carbide

❖ **Cu:** (0.25 – 2.5%)   Cu graphitizer = 1/5% Si

Cu break up Fe_3C + Strengthen the matrix.

❖ **Mo:** (0.25 – 1.25%)

Mo improve →
- **Fatigue** } **Strength**
- **Tensile** } **Strength**
- **Transverse**
- **Hardness**
- **Heat resistance + retards transformation of (γ) → increase hardenability**

Cast Iron (CI):

❖ **V:** (0.1 – 0.25%) added → Very powerful Carbide form.
→ Stabilizer Fe_3C.
→ Reduce graphitization.

V increase → Tensile Strength
→ Transverse Strength
→ Hardness

❖ **Ni:** (0.5 – 6%) → Graphitizer (1/2 as effect as Si)

Retard γ transformation

Stabilizer.

Ni + (1% Mo) → microstructure of matrix tends to be Bainite (BHN = 385)

4% Ni + 1.5% Cr → excellent abrasion resistance to white CI because the primary dendrites + originally γ ⇒ Martensite (M).

Combination of Fe_3C in Martensite ⇒ increases hardness to 600 – 700 BH.
+ Good strength toughness.

(14 – 38)% Ni added to Gray Iron ⇒ ↑ heat resistance + Corrosion
+ ↓ expansivity.

(Because of Ni transform the matrix → γ)

Cast Iron (CI):

Summary of Cast Iron microstructures and the phases existing at various temperatures.