Study of Wear Resistant Steels for Excavator Application

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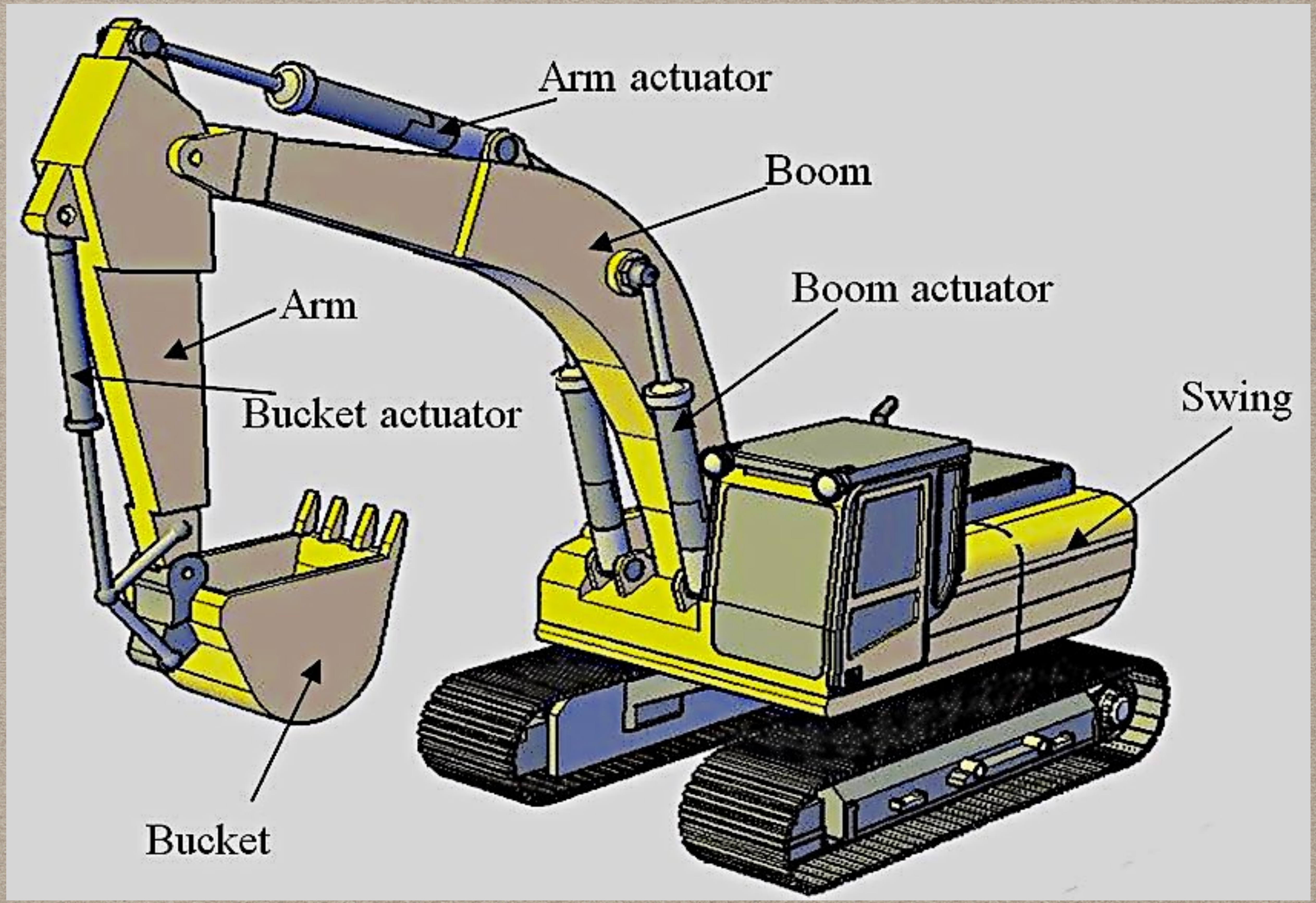
00. Flow of Topics

01. What are Excavators ?

Excavators are heavy construction equipment consisting of a boom, dipper (or stick), bucket and cab on a rotating platform known as the "house". The house sits atop an undercarriage with tracks or wheels.



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02. Excavator's Applications

Excavators are versatile heavy machinery used in a wide range of applications across various industries due to their ability to dig, lift, and move large amounts of materials.

Applications

- Construction
- Landscaping and Earthmoving
- Road and Highway Construction
- Forestry
- Utility and Infrastructure Maintenance
- Dredging
- Waste Management
- Demolition
- Pipe and Cable Installation
- Quarrying

02. Excavator’s applications

1) **Construction:** Excavators are commonly used in construction projects for tasks such as digging trenches, foundations, and holes, as well as for grading and site preparation.

2) **Dredging:** Excavators with long arms and buckets are used for dredging operations in bodies of water. They remove sediment, debris, and other materials to deepen waterways, create channels, and maintain ports.

3) **Landscaping and Earthmoving:** Excavators are used in landscaping projects to shape terrain, create ponds, install drainage systems, and move large quantities of soil and materials.

4) **Waste Management:** Excavators are used in waste management facilities to handle and move solid waste, load materials into shredders or compactors, and manage landfill operations

5) **Road and Highway Construction:** Excavators are used to build and maintain roads, highways, and other transportation infrastructure. They can be used for digging and shaping roadbeds, as well as for tasks like laying pipes and cables.

02. Excavator’s applications

6) **Demolition:** Excavators equipped with specialized attachments are used for controlled demolition of buildings and structures. They can efficiently tear down structures and clear debris.

7) **Forestry:** In the forestry industry, excavators equipped with attachments like grapples and mulchers are used for tasks such as clearing land, processing wood, and handling logs.

8) **Pipe and Cable Installation:** Excavators are used to dig trenches for installing pipelines, cables, and conduits for utilities like water, gas, electricity, and telecommunications.

9) **Utility and Infrastructure Maintenance:** Excavators are employed in utility maintenance tasks, such as repairing and installing underground pipes, cables, and infrastructure components.

10) **Quarrying:** Excavators are used in quarry operations to extract stone, gravel, and other construction materials from the earth.

Excavator on the Construction Site

https://www.google.com/url?sa=i&url=https://multico.com.ph/blog/uses-of-an-excavator/&psig=AOvVaw1Zprmgu59GAalPcrs_9U9X&ust=17010641[illegible]190000&source=images&cd=vfe&opi=[illegible]

03. Why steel is used for excavator applications?

Steel is commonly used for excavator applications due to its combination of **mechanical properties**, **durability**, and **cost-effectiveness**.
Here are some reasons why steel is the material of choice for excavator construction:

- 01 Wear Resistance
- 02 Strength and Toughness
- 03 Structural Integrity
- 04 Wide Temperature Range
- 05 Recyclability
- 06 Impact Resistance
- 07 Machinability
- 08 Experience and Tradition
- 09 Customisation
- 10 Availability and Cost

03. Reasons

1) **Wear Resistance:** Excavators operate in abrasive environments where components like buckets, teeth, and cutting edges are subjected to significant wear. Wear-resistant steels, often containing specialised carbides and alloys, are used to extend the lifespan of these components and reduce maintenance costs.

2) **Strength and Toughness:** Steel offers high strength and toughness, making it suitable for the heavy-duty nature of excavator operations. It can withstand the loads, impacts, and stresses that excavators encounter during digging, lifting, and moving materials.

3) **Structural Integrity:** Steel provides the necessary structural integrity to support the weight of the machine and the loads it handles. Its high strength-to-weight ratio allows for robust construction without excessive weight.

4) **Wide Temperature Range:** Excavators operate in diverse environments, from freezing cold to scorching heat. Steel maintains its mechanical properties across a wide temperature range, making it suitable for various operating conditions.

5) **Recyclability:** Steel is highly recyclable, contributing to environmental sustainability. At the end of an excavator's life cycle, the steel components can be recycled and reused
in other applications.

03. Reasons

1) **Impact Resistance:** Excavators are designed to handle various types of impacts, such as when digging into hard soil or encountering rocks. Steel's ability to absorb and distribute impact forces helps protect the machine's structural integrity.

2) **Machinability:** Steel can be easily machined, welded, and formed, allowing for the fabrication of complex excavator components and structures. This versatility in manufacturing processes makes it convenient for producing different parts of the excavator.

3) **Experience and Tradition:** The construction industry has a long history of using steel for heavy machinery due to its proven performance and reliability. This accumulated experience informs the selection of steel for excavator applications.

4) **Customisation:** Steel's composition and properties can be tailored through alloying and heat treatment to meet specific requirements. This allows manufacturers to optimise the material for various excavator applications, balancing factors like hardness, toughness, and wear resistance.

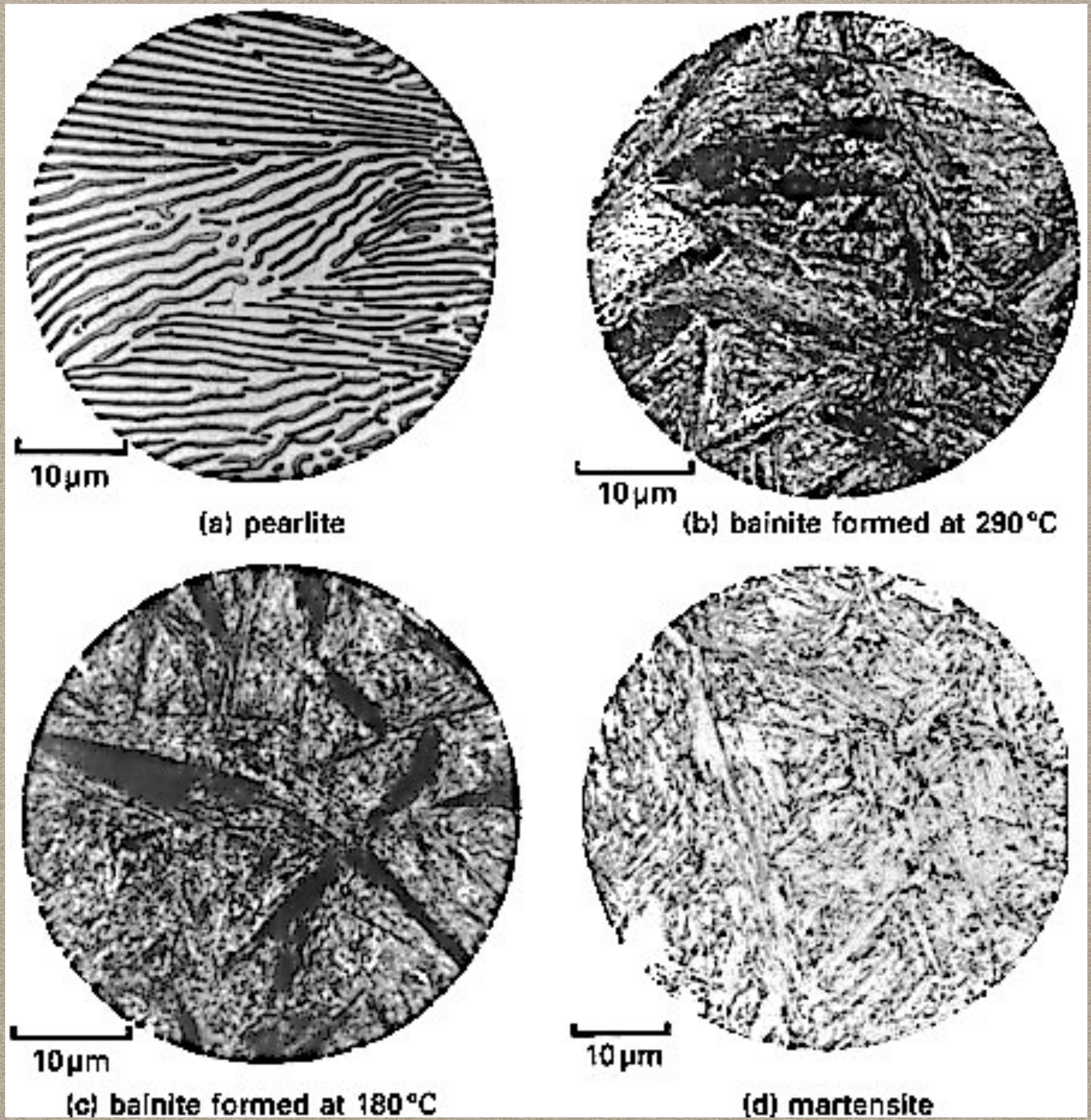
5) **Availability and Cost:** Steel is widely available and relatively cost-effective compared to some other materials with similar properties. This makes it a practical choice for manufacturing excavators, especially when considering factors like production volume and material costs.

04. Phases present in microstructures of steel

Martensite	Austenite
Ferrite	Pearlite
Carbide	Bainite

04. Phases present in microstructures of steel

1. **Martensite:** Martensite is a hard and brittle phase that forms when steel is rapidly quenched from high temperatures. It has a body-centered tetragonal crystal structure and provides high hardness and wear resistance. However, it lacks the ductility of other phases and can be prone to brittleness.
2. **Austenite**: Austenite is a face-centered cubic phase that is present at elevated temperatures. It can transform into martensite during quenching or cooling, contributing to the hardness and wear resistance of the steel.
3. **Ferrite**: Ferrite is a relatively soft and ductile phase with a body-centered cubic crystal structure. It provides toughness and impact resistance to wear-resistant steels, balancing the hardness of other phases.
4. **Pearlite**: Pearlite is a lamellar microstructure composed of alternating layers of ferrite and cementite (an iron carbide). It provides a balance between strength and ductility, contributing to the overall mechanical properties of the steel.
5. **Carbides**: Various types of carbides are often present in wear-resistant steels to enhance hardness and wear resistance. Common carbides include:
    1. **Chromium Carbides**: These carbides are formed when chromium combines with carbon. They are extremely hard and contribute significantly to wear resistance.
    2. **Vanadium Carbides**: Vanadium carbides enhance hardness and wear resistance, especially at high temperatures.
    3. **Molybdenum Carbides**: Molybdenum carbides contribute to high- temperature strength and wear resistance.
6. **Bainite**: Bainite is a microstructure that forms between the martensite and pearlite temperature ranges. It provides a combination of strength, toughness, and wear resistance, making it desirable in certain wear-resistant applications.



(a) pearlite

(b) bainite formed at 290°C

(c) bainite formed at 180°C

(d) martensite

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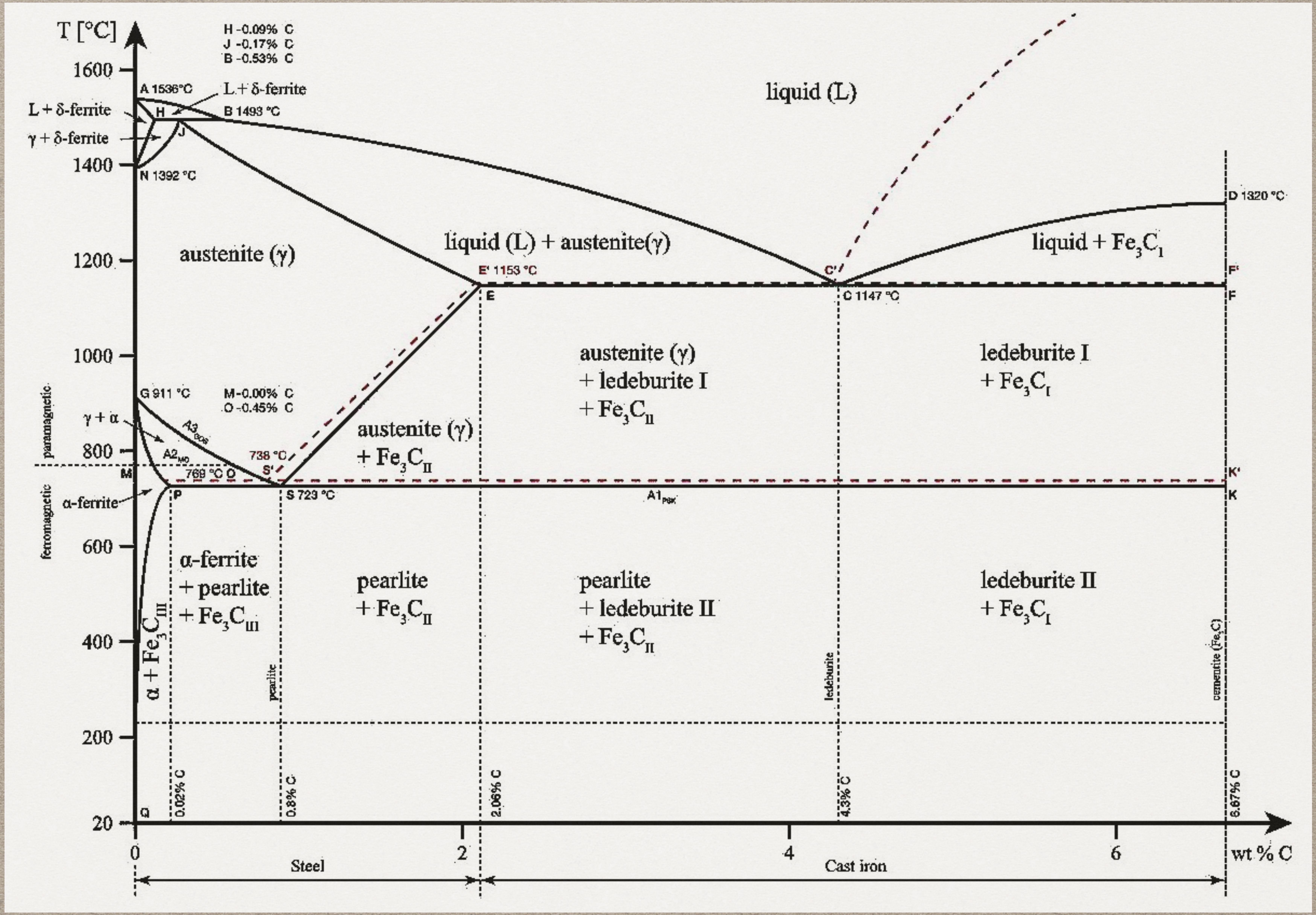
05. Iron-Carbon Phase Diagram



https://www.google.com/url?sa=i&url=https://fractory.com/iron-carbon-phase-diagram/&psig=AOvVaw1dx1FL6wnLhvk2UMih7sO0&ust=1701064562684000&source=images&cd=vfe&opi=89978449&ved=0CBQQjhxqFwoTCJDI4rn94IIDFQAAAAAdAAAAABAE

06. Our Objective

To lengthen the life of this steel

Some Strengthening Mechanisms

- Solid Solution
- Strain Hardening
- Grain Boundary
- Precipitate and Dispersoid

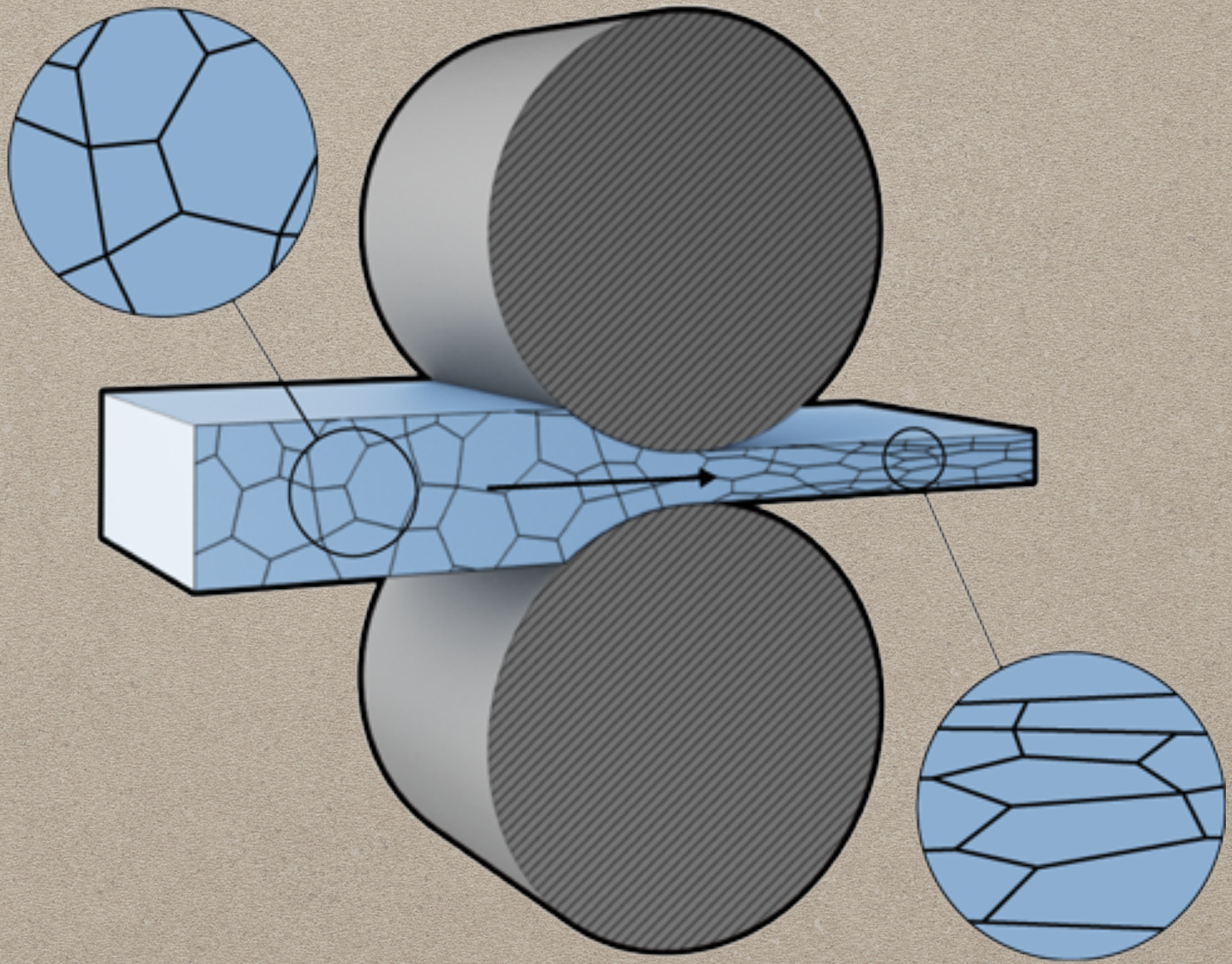
07. Some Strengthening Mechanism

1) **Solid solution** : (increase in lattice friction) by adding interstitial and substitutional alloying elements.

2) **Strain hardening** : (dislocation density strengthening) increase point defect and dislocation density (Cold work increases Yield stress but decreases the % elongation, i.e. ductility).

3) **Grain boundary** : (grain boundary strengthening) grain boundaries provide an impediment to the motion of dislocations (Hall-Petch hardening).

4) **Precipitation/dispersion hardening** : Introduce precipitates or inclusions in the path of dislocations, which impede the motion of dislocations.



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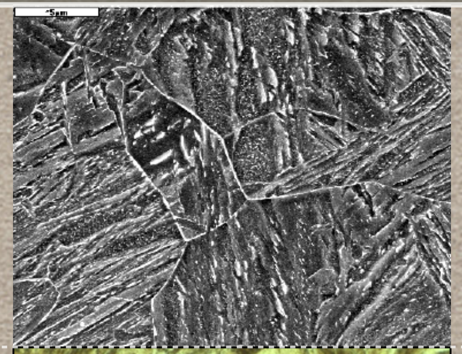
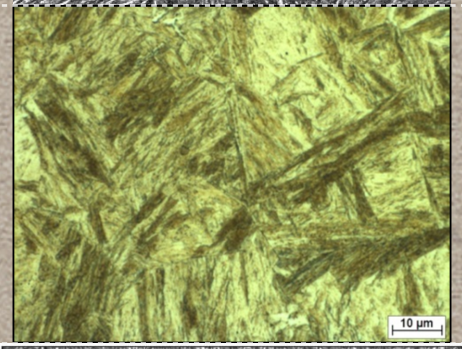
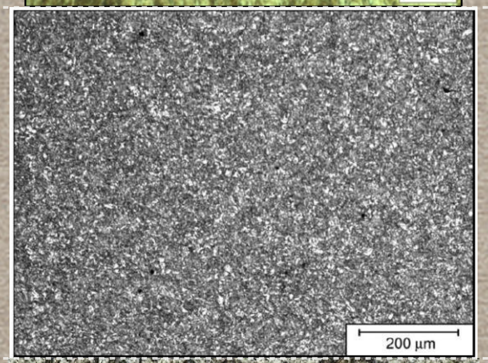
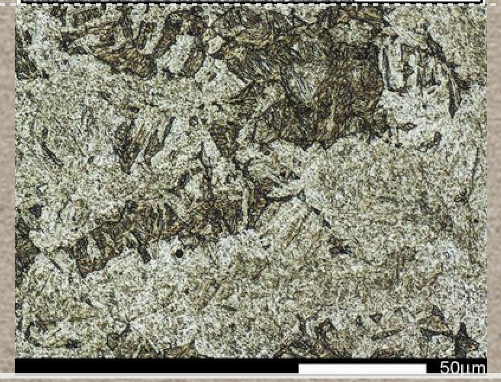
Cold Rolling

08. Some details about currently used steels

The data mentioned here is taken from the official website of the manufacturing companies of these steels. The companies manufacturing these steels also manufacture many other types of steel but the ones mentioned here are only those which are used for excavator applications.

S No.	Name	Composition	Microstructure	Mechanical Properties	Manufacturing Process	Remarks
1	Hardox 400	Carbon(C) : 0.32% Manganese(Mn) : 1.60% Silicon (Si) : 0.70% Sulfur(S) : 0.010% Phosphorus(P) : 0.025% Chromium(Cr) : 2.50% Nickel(Ni) : 1.50% Molybdenum(Mo) : 0.60% Boron(B) : 0.004%		Hardness(HBW) : 370-430 Yield Strength (MPa): 1100	Quenched and Tempered	Can be used for bucket, excavator teeth and loader shovels.
2	Hardox 450	Carbon(C) : 0.26% Manganese(Mn) : 1.60% Silicon (Si) : 0.70% Sulfur(S) : 0.010% Phosphorus(P) : 0.025% Chromium(Cr) : 1.40% Nickel(Ni) : 1.50% Molybdenum(Mo) : 0.60% Boron(B) : 0.005%		Hardness(HBW) : 425-475 Yield Strength (MPa): 1250	Quenched and Tempered	Can be used for digging buckets, cutting edges, and crusher components.
3	Hardox 500	Carbon(C) : 0.30% Manganese(Mn) : 1.30% Silicon (Si) : 0.40% Sulfur(S) : 0.010% Phosphorus(P) : 0.020% Chromium(Cr) : 2.20% Nickel(Ni) : 2.0% Molybdenum(Mo) : 0.40% Boron(B) : 0.005%		Hardness(HBW) : 470-530 Yield Strength (MPa): 1400	Quenched and Tempered	Can be used for buckets, dump truck bodies, and hammers.
4	Hardox 600	Carbon(C) : 0.47% Manganese(Mn) : 1.50% Silicon (Si) : 0.70% Sulfur(S) : 0.010% Phosphorus(P) : 0.015% Chromium(Cr) : 1.20% Nickel(Ni) : 2.50% Boron(B) : 0.01% Molybdenum(Mo) : 0.70% Boron(B) : 0.005%		Hardness(HBW) : 570-640	Quenched	Can be used for wear liners for chutes and hoppers, as well as shredder components.

08. Some details about currently used steels

S No.	Name	Composition	Mechanical Properties	Manufacturing Process
6	Raex 400	Carbon(C) : 0.23% Manganese(Mn) : 1.70% Silicon (Si) : 0.80% Sulfur(S) : 0.015% Phosphorus(P) : 0.025% Chromium(Cr) : 1.50% Nickel(Ni) : 1.00% Molybdenum(Mo) : 0.50% Boron(B) : 0.005%	Hardness(HBW) : 360-440 Yield strength(MPa) : 1100 Tensile strength(MPa) : 1300 Elongation(%) : 10	Quenched
7	Raex 450	Carbon(C) : 0.26% Manganese(Mn) : 1.70% Silicon (Si) : 0.80% Sulfur(S) : 0.015% Phosphorus(P) : 0.025% Chromium(Cr) : 1.50% Nickel(Ni) : 1.00% Molybdenum(Mo) : 0.50% Boron(B) : 0.005%	Hardness(HBW) : 420-500 Yield strength(MPa) : 1200 Tensile strength(MPa) : 1450 Elongation(%) : 9	Quenched
8	Raex 500	Carbon(C) : 0.30% Manganese(Mn) : 1.70% Silicon (Si) : 0.80% Sulfur(S) : 0.015% Phosphorus(P) : 0.025% Chromium(Cr) : 1.50% Nickel(Ni) : 1.00% Molybdenum(Mo) : 0.50% Boron(B) : 0.005%	Hardness(HBW) : 470-540 Yield strength(MPa) : 1300 Tensile strength(MPa) : 1600 Elongation(%) : 8	Quenched
9	Brinar 400	Carbon(C) : 0.18% Manganese(Mn) : 2.0% Silicon (Si) : 0.50% Sulfur(S) : 0.005% Phosphorus(P) : 0.015% Chromium(Cr) : 1.55% Molybdenum(Mo) : 0.60% Boron(B) : 0.005% Aluminium(Al) : 0.100%	Hardness(HBW) : 360-440 Yield strength(MPa) : 1100 Tensile strength(MPa) : 1300 Elongation(%) : 8	Quenched and Tempered
10	Brinar 450	Carbon(C) : 0.22% Manganese(Mn) : 1.50% Silicon (Si) : 0.40% Sulfur(S) : 0.005% Phosphorus(P) : 0.015% Chromium(Cr) : 1.20% Molybdenum(Mo) : 0.40% Boron(B) : 0.005% Aluminium(Al) : 0.100	Hardness(HBW) : 450 Yield strength(MPa) : 1135 Tensile strength(MPa) : 1390 Elongation(%) : 9	Quenched and Tempered

08. Some details about currently used steels

S No.	Name	Composition	Mechanical Properties
11	Brinar 500	Carbon(C) : 0.280% Manganese(Mn) : 1.50% Silicon (Si) : 0.80% Sulfur(S) : 0.005% Phosphorus(P) : 0.02% Chromium(Cr) : 1.50% Molybdenum(Mo) : 0.40% Aluminium(Al) : 0.100%	Hardness(HBW) : 480 Yield strength(MPa) : 1350 Tensile strength(MPa) : 1500 Elongation(%) : 8
14	AR400	Carbon(C) : 0.17% Manganese(Mn) : 1.50% Silicon (Si) : 0.50% Sulfur(S) : 0.005% Phosphorus(P) : 0.025% Chromium(Cr) : 0.60% Molybdenum(Mo) : 0.20% Boron(B) : 0.003%	Tensile strength(ksi) : 194 Yield Strength (ksi) : 156 Elongation (%): 19-23
15	AR450	Carbon(C) : 0.25% Manganese(Mn) : 1.35% Silicon (Si) : 0.55% Sulfur(S) : 0.005% Phosphorus(P) : 0.025% Chromium(Cr) : 0.55% Molybdenum(Mo) : 0.65% Boron(B) : 0.003% Nickel(Ni) : 1.00%	Tensile strength(ksi) : 170 Yield Strength (ksi) : 206 Elongation (%): 18-23 Hardness(BHN) : 400-477
16	AR500	Carbon(C) : 0.31% Manganese(Mn) : 1.95% Silicon (Si) : 0.65% Sulfur(S) : 0.005% Phosphorus(P) : 0.025% Chromium(Cr) : 0.75% Molybdenum(Mo) : 0.75% Boron(B) : 0.003% Nickel(Ni) : 1.00%	Tensile strength(ksi) : 225 Yield Strength (ksi) : 220 Elongation (%): 12 Hardness(BHN) : 477-550
17	SSAB DOMEX 355ML	Carbon(C) : 0.14% Manganese(Mn) : 1.60% Silicon (Si) : 0.50% Sulfur(S) : 0.015% Phosphorus(P) : 0.020% Aluminium(Al) : 0.02% Niobium(Nb) : 0.05% Vanadium(V) : 0.05% Titanium(Ti) : 0.05%	Yield strength(MPa) : 345 Tensile strength(MPa) : 470-630 Elongation(%) : 22
18	SSAB DOMEX 420ML	Carbon(C) : 0.14% Manganese(Mn) : 1.60% Silicon (Si) : 0.50% Sulfur(S) : 0.015% Phosphorus(P) : 0.020% Aluminium(Al) : 0.02% Niobium(Nb) : 0.05% Vanadium(V) : 0.10% Titanium(Ti) : 0.05%	Yield strength(MPa) : 420 Tensile strength(MPa) : 520-680 Elongation(%) : 19

08. Some details about currently used steels

S No.	Name	Composition	Mechanical Properties
19	SSAB DOMEX 460ML	Carbon(C) : 0.14% Manganese(Mn) : 1.70% Silicon (Si) : 0.50% Sulfur(S) : 0.015% Phosphorus(P) : 0.020% Aluminium(Al) : 0.02% Niobium(Nb) : 0.05% Vanadium(V) : 0.10% Titanium(Ti) : 0.05%	Yield strength(MPa) : 460 Tensile strength(MPa) : 540-720 Elongation(%) : 17
20	SSAB DOMEX 500ML	Carbon(C) : 0.18% Manganese(Mn) : 1.70% Silicon (Si) : 0.50% Sulfur(S) : 0.010% Phosphorus(P) : 0.020% Aluminium(Al) : 0.02% Niobium(Nb) : 0.05% Vanadium(V) : 0.12% Titanium(Ti) : 0.05%	Yield strength(MPa) : 500 Tensile strength(MPa) : 570-760 Elongation(%) : 16
21	SSAB DOMEX 240YP	Carbon(C) : 0.12% Manganese(Mn) : 0.80% Silicon (Si) : 0.03% Sulfur(S) : 0.025% Phosphorus(P) : 0.025%	Yield strength(MPa) : 240 Tensile strength(MPa) : 360-460 Elongation(%) : 28
22	SSAB DOMEX 315MC	Carbon(C) : 0.10% Manganese(Mn) : 1.30% Silicon (Si) : 0.50% Sulfur(S) : 0.010% Phosphorus(P) : 0.025% Aluminium(Al) : 0.015% Niobium(Nb) : 0.09% Vanadium(V) : 0.20% Titanium(Ti) : 0.15%	Yield strength(MPa) : 315 Tensile strength(MPa) : 390-510 Elongation(%) : 24

09. What have people done up to this point?

1. **Multiphase steel with improved impact-abrasive wear resistance in comparison with conventional Hadfield steel**
   This study examines the properties of a novel multiphase steel and a typical Hadfield steel (Mn13Cr2) following its casting in a high-frequency induction furnace. The following were the key findings of this research paper:

   1. In comparison to typical Hadfield steel Mn13Cr2, the multiphase steel exhibits superior characteristics such as **increased** tensile strength, micro-hardness, work hardening capability, and impact-abrasive wear resistance. Nevertheless, it should be noted that the multiphase steel exhibits a comparatively **lower impact energy**, as evidenced by the Charpy V-notch test .

   2. The primary mechanisms responsible for strengthening were identified as **phase transition**, **grain refining**, and **high density dislocations** in the case of the multiphase steel. In contrast, the strengthening of Mn13Cr2 was attributed to the interplay between **twining** and **dislocation walls**.

   3. According to the findings derived from X-ray diffraction (XRD) and transmission electron microscopy (TEM) analyses, it was observed that a phase change occurred under conditions of high impact energy. Specifically, the transformation involved the conversion of **soft retained austenite into hard twinned martensite**, accompanied by grain refinement and the generation of high-density dislocations. As a result of these transformations, a significant enhancement in microhardness and wear resistance was observed.

   4. The wear mechanisms observed in the multiphase steel include **press-in particle**, **micro-voids**, and d**elaminated crater**.

   5. The improvement of wear resistance mostly relies on the interplay between twinning and dislocation walls. There was no observable occurrence of martensite transformation in any of the wear conditions examined. The wear mechanisms observed in this study include **adhesion**, **crater formation**, and **micro-crack propagation**.

1)

09. What have people done up to this point?

2. High strength-toughness combination of a low-carbon medium-manganese steel plate with laminated microstructure and retained austenite

In this experiment three distinct grain architectures of low-carbon medium-manganese steel were fabricated using a carefully regulated rolling process. The following were the key findings of this research paper:

(1) The microstructure of the laminated material exhibited a pronounced fiber texture with a strong orientation along the <110> direction parallel to the rolling direction (RD). This texture consisted of ultra-fine elongated ferrite, retained austenite, and martensite phases, which were stacked in an alternating pattern along the RD.

(2) The occurrence of interface-decohesion delamination can be attributed to the combined effect of ultra-fine elongated laminated microstructure and weak interfaces like PAGBs and/or boundaries of ferrite-martensite. The existence of numerous {001} cleavage planes normal to the v-notch direction is helpful in formation of the quasi-cleavage delamination at cryogenic temperature.

(3) The steel possessing an equiaxed grain structure demonstrated a comparatively modest tensile strength of 960 MPa and a significantly deficient low-temperature toughness of around 8 J at a temperature of -196 °C. The steel with a laminated microstructure exhibited notable improvements in many mechanical properties. Specifically, it demonstrated an increased upper shelf energy exceeding 450 J, a low-temperature toughness of around 105 J at -196 °C, and an enhanced tensile strength of 1145 MPa.

(4) The incorporation of a laminated microstructure in the steel resulted in a notable enhancement of its strength and toughness in the rolling direction (RD), hence contributing to the observed high tensile strength to a certain degree.

(5) The occurrence of delamination can be attributed to the combined influence of several factors, including the ultra-fine elongated laminated microstructure, potential interface decohesion, and the presence of several {001} cleavage planes.

(6) Interface-decohesion delamination suppressed the crack propaga- tion along the v-notch direction and thus increased resistance to impact fracture, which finally resulted in greater plastic deformation and higher upper shelf energy. TRIP effect is believed to be an additional mechanism to improve the lower shelf energy, besides delamination toughening, by blunting propagation of microcracks.

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Thank you