ME 216 – Engineering Materials II

Chapter 1

Introduction to Engineering Metallurgy & Materials

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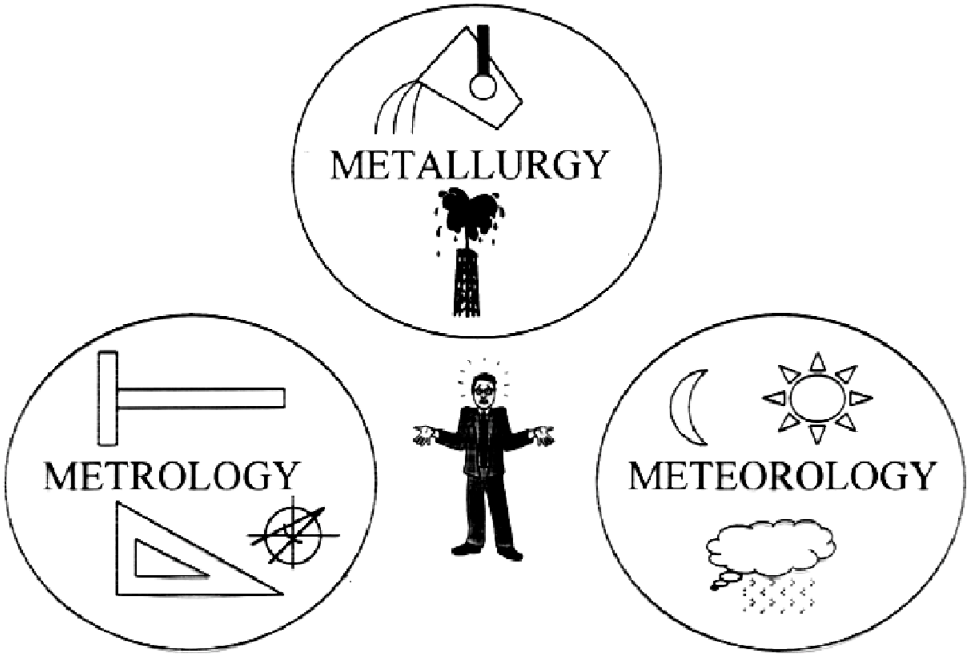
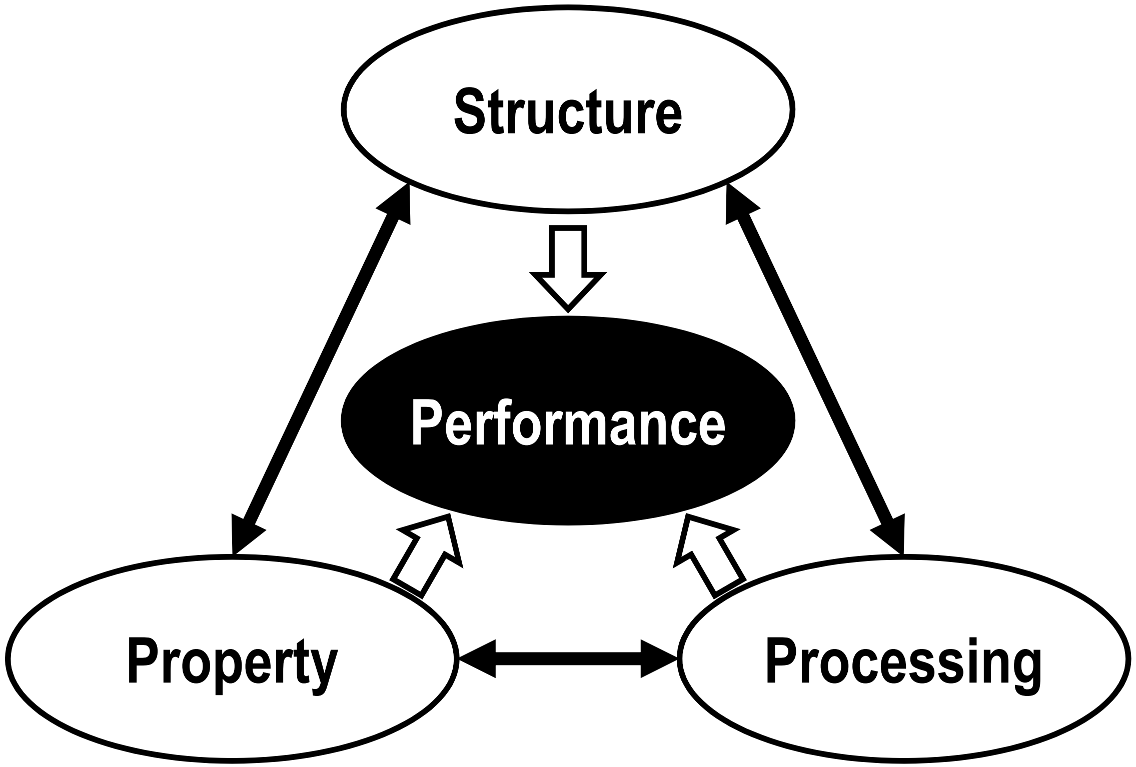
What is Metallurgy?

- It is **the art of making metals and alloys** in various forms with certain properties suitable for practical use.

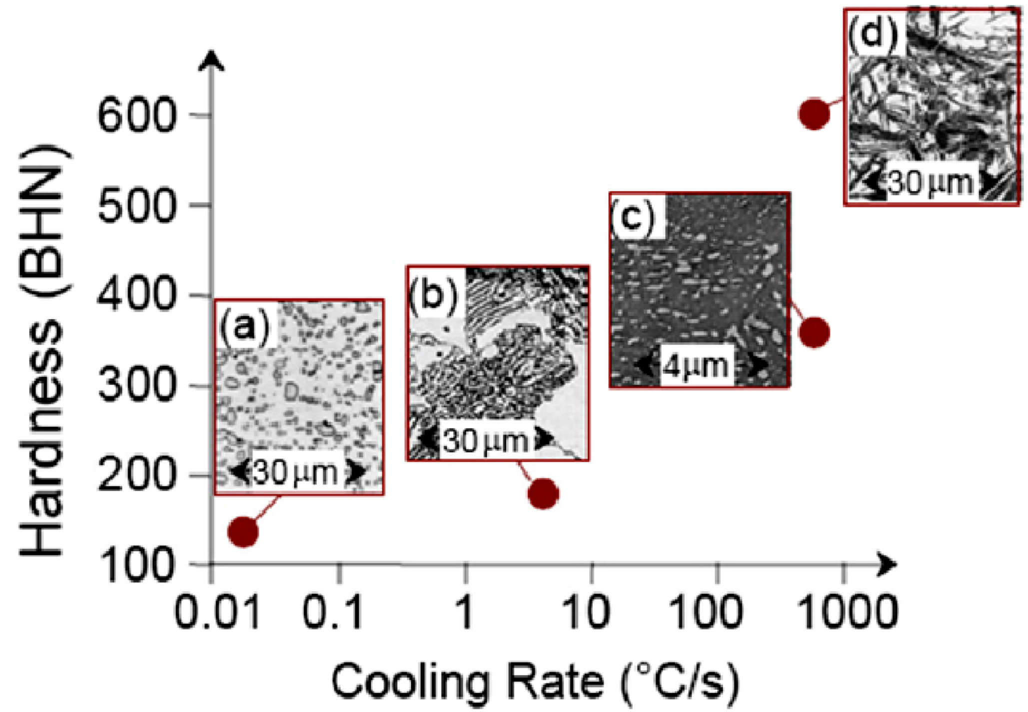


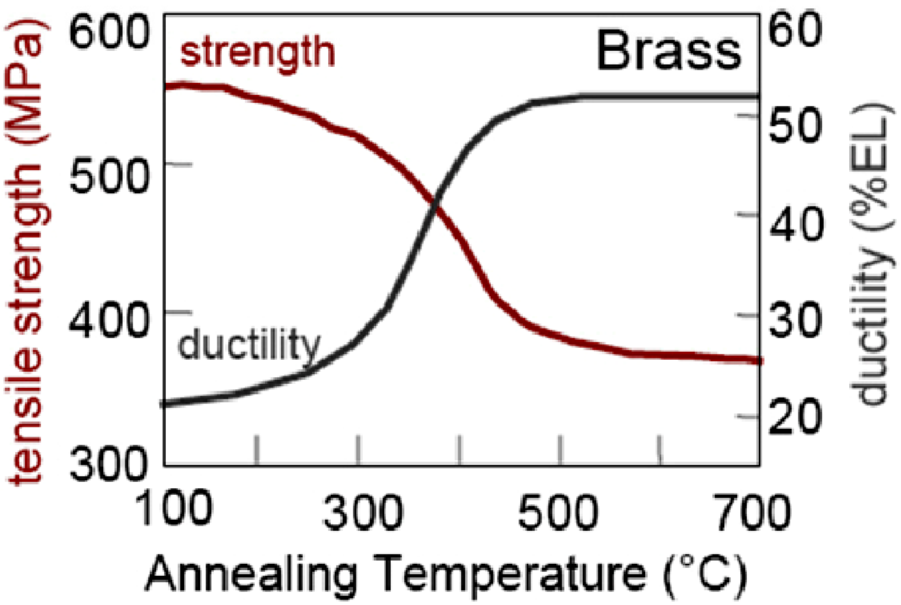
- In a broader meaning; it is **the material science** dealing with structure-property-processing cycle of materials for providing **the optimum material performance**.

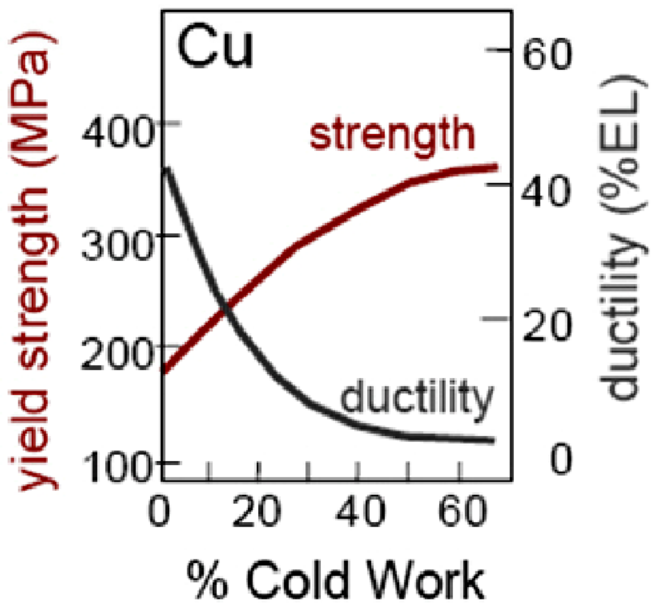


Structure-Property-Processing Relationships

- **Processing can change structure**
  (e.g. structure vs cooling rate of steel).
- **Properties depend on structure**
  (e.g. hardness vs structure of steel).
- **Trade-off between property and processing**
  (e.g. strength tends to be inverse to ductility).

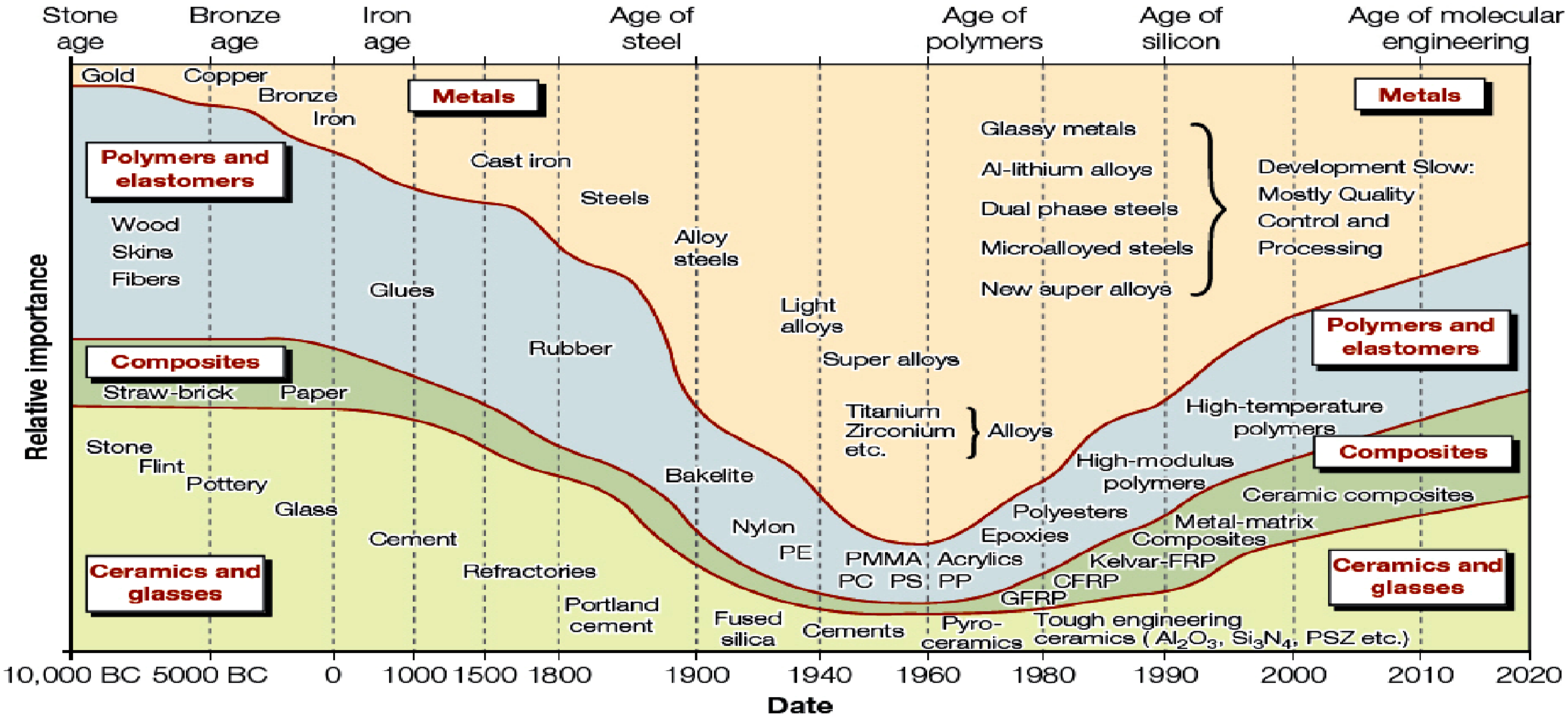






The images are courtesy of: Fundamentals of Materials Science and Engineering, Callister & Rethwisch, 2012

- Many materials and their alloys had emerged throughout the history.
- For several centuries, few materials and alloys were sufficient to meet most human needs.
- Today, various materials and their combinations are being used for different applications.



The evolution of engineering materials with time (Courtesy of: Materials Selection in Mechanical Design, Ashby, 2011)

PROPERTY	METALS	POLYMERS	CERAMICS	COMPOSITES	ELECTRONIC
Definition	▪ Inorganic substances ▪ Composed of one or more metallic elements ▪ May contain some non-metallic elements	▪ Consist of organic (carbon containing) long molecular chains or networks	▪ Inorganic & non-metallic solids or supercooled liquids ▪ Processed or used at high temperatures	▪ Combination of two or more materials ▪ To support a weakness in one material by strength in another	▪ Not a major material group by volume ▪ Important material type for advanced engineering technology
Structure	▪ Crystalline structure (atoms are arranged in an orderly manner)	▪ Mostly non-crystalline ▪ Some consist of mixture of crystalline & non-crystalline regions	▪ Can be crystalline, non-crystalline, or mixtures of both	▪ Fibrous (fibers in a matrix) ▪ Particulate (particles in a matrix)	▪ Pure silicon (can be miniaturized to 0.5 cm^2)
Thermal	▪ Good conductor	▪ Temp. sensitive	▪ Good insulator	▪ Improved	▪ N/A
Electrical	▪ Good conductor	▪ Good insulator	▪ Good insulator	▪ Improved	▪ Outstanding
Strength	▪ Strong	▪ Weak	▪ High-temp. strength	▪ Improved	▪ N/A
Ductility	▪ Ductile	▪ Varies	▪ Brittle	▪ Improved	▪ N/A
Density	▪ Heavy	▪ Light	▪ Varies	▪ Improved	▪ N/A
Hardness	▪ Varies	▪ Soft	▪ Very hard	▪ Improved	▪ N/A

- In engineering design, one of the most important aspects is the selection of a material from which a part will be produced.
- There are currently **over 100,000** metallic alloys and non-metallic engineering materials.
- In general, material selection is based on **past experiences**. What worked before obviously is a solution, but it is **not necessarily the optimum solution**.
- **In the past, materials were selected from handbooks** with limited choices on the basis of limited property data. **Today, that is an unacceptable approach** for all cases.
- Therefore, material selection can be simple or complicated task based on the application.

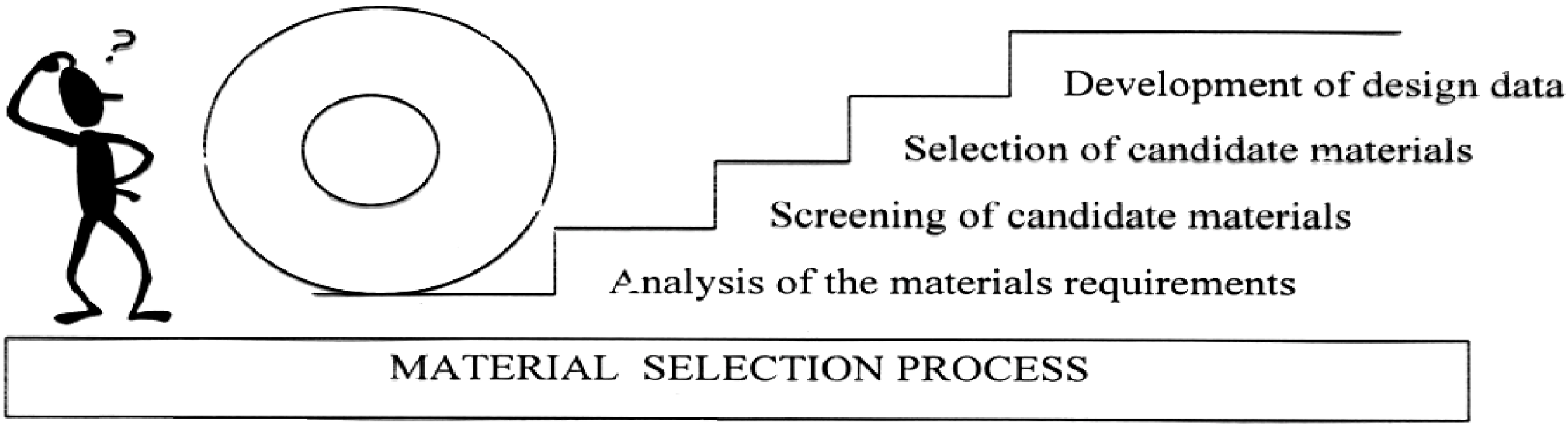
Functional (Performance) Requirements

- To satisfy the need, designer must determine **essential and desirable features** of design.
- These are expressed in the form of **"functional requirements"** concerning performance characteristics of materials (i.e. **material properties**).
- It is not possible to select a material for one property alone.
- Thus, as it is impossible to satisfy all requirements to the same degree, material properties are arranged in **the order of importance** to identify the areas of compromise.

Properties of Materials (Functional Requirements)

- **Mechanical**
  - Strength
  - Stiffness
  - Ductility
  - Toughness
  - Hardness
  - Fatigue
  - Impact
  - Shear
- **Physical**
  - Crystal structure
  - Density
  - Melting point
  - Viscosity
  - Porosity
  - Reflectivity
  - Transparency
  - Dimensional stability
- **Chemical**
  - Corrosion
  - Oxidation
  - Embrittlement
- **Electrical**
  - Conductivity
  - Magnetic
  - Dielectric
  - Hysteresis
- **Thermal**
  - Conductivity
  - Specific heat
  - Expansion
  - Emissivity
  - Absorptivity
- **Nuclear**
  - Half-life
  - Cross section
  - Stability
- **Fabrication**
  - Castability
  - Machinability
  - Formability
  - Weldability
  - Hardenability
  - Heat treatibility
  - Compactibility

- Material selection is **a problem solving process**, which consists of the following steps:
- Analysis of the materials requirements: Determine the conditions of service and environment that the product must withstand. Translate them into critical material properties.
- Screening of candidate materials: Compare the necessary properties with a large material property database to select a few materials that look promising for the application.
- Selection of candidate materials: Analyze candidate materials in terms of trade-offs (product performance, cost, fabricability, availability) to select the best material for the application.
- Development of design data: Determine experimentally key material properties for selected material to obtain statistically reliable measures of material performance under the specific conditions expected to be encountered in service.

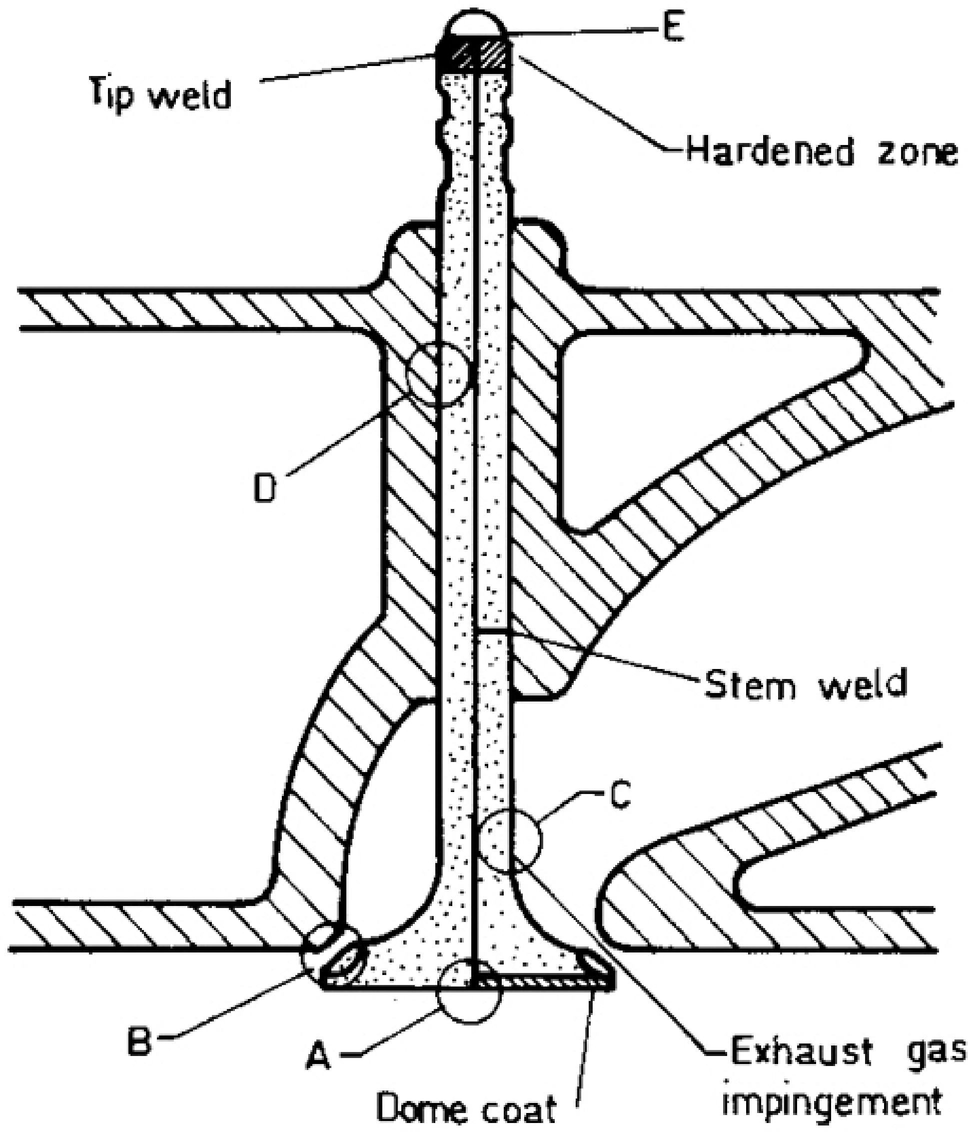


Selection Example: Exhaust Valve

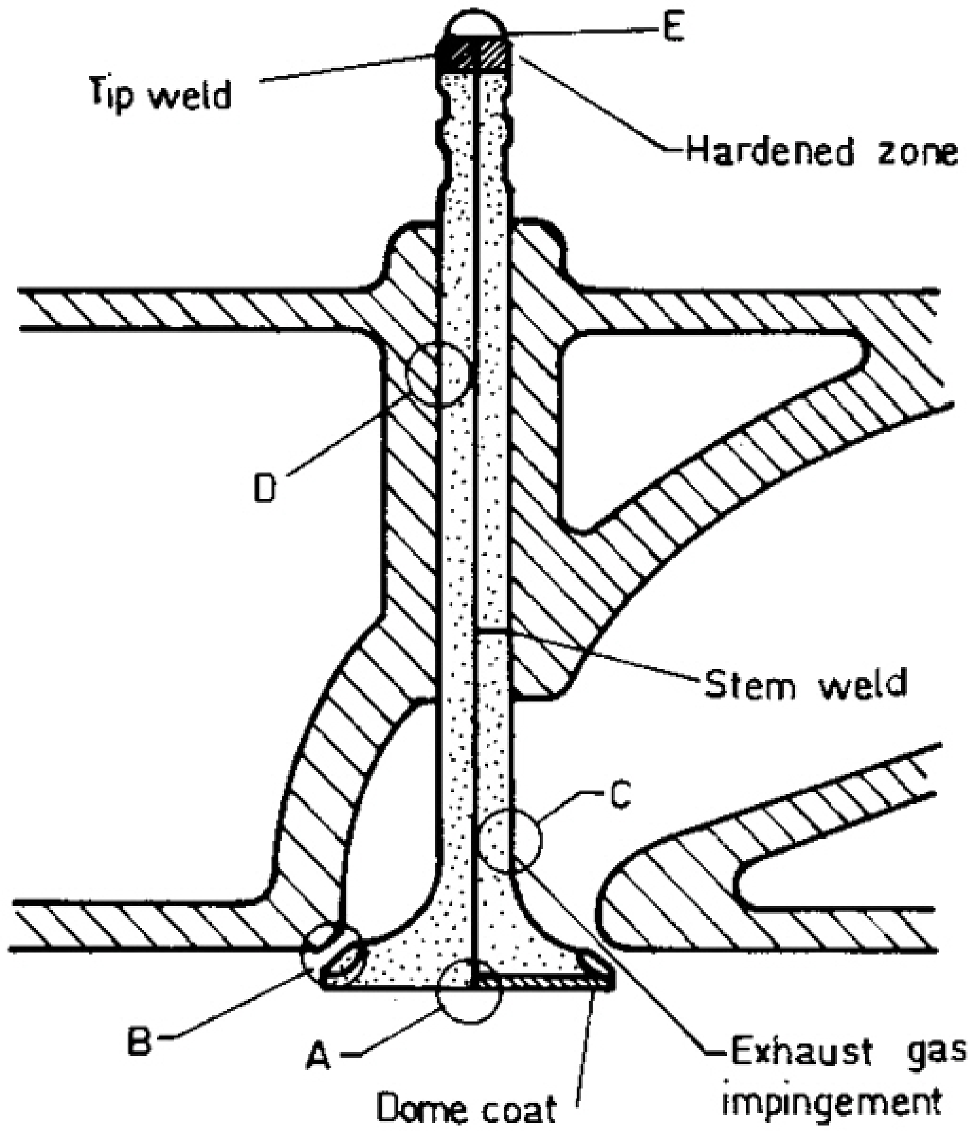
- The automobile is a complex engineering system, and the recent trends reflect the great effort to decrease fuel consumption of cars by adopting weight saving materials.

- A good example for complex materials system used in a difficult environment is **the exhaust valve** in an internal combustion engine. Valve materials must have excellent corrosion and oxidation resistance properties to resist "burning" in the temperature range of 700-900 °C.

- Therefore, the valves must have:
  - **sufficient high temp. fatigue strength and creep resistance** to resist failure.
  - **suitable hot hardness** to resist wear and abrasion.

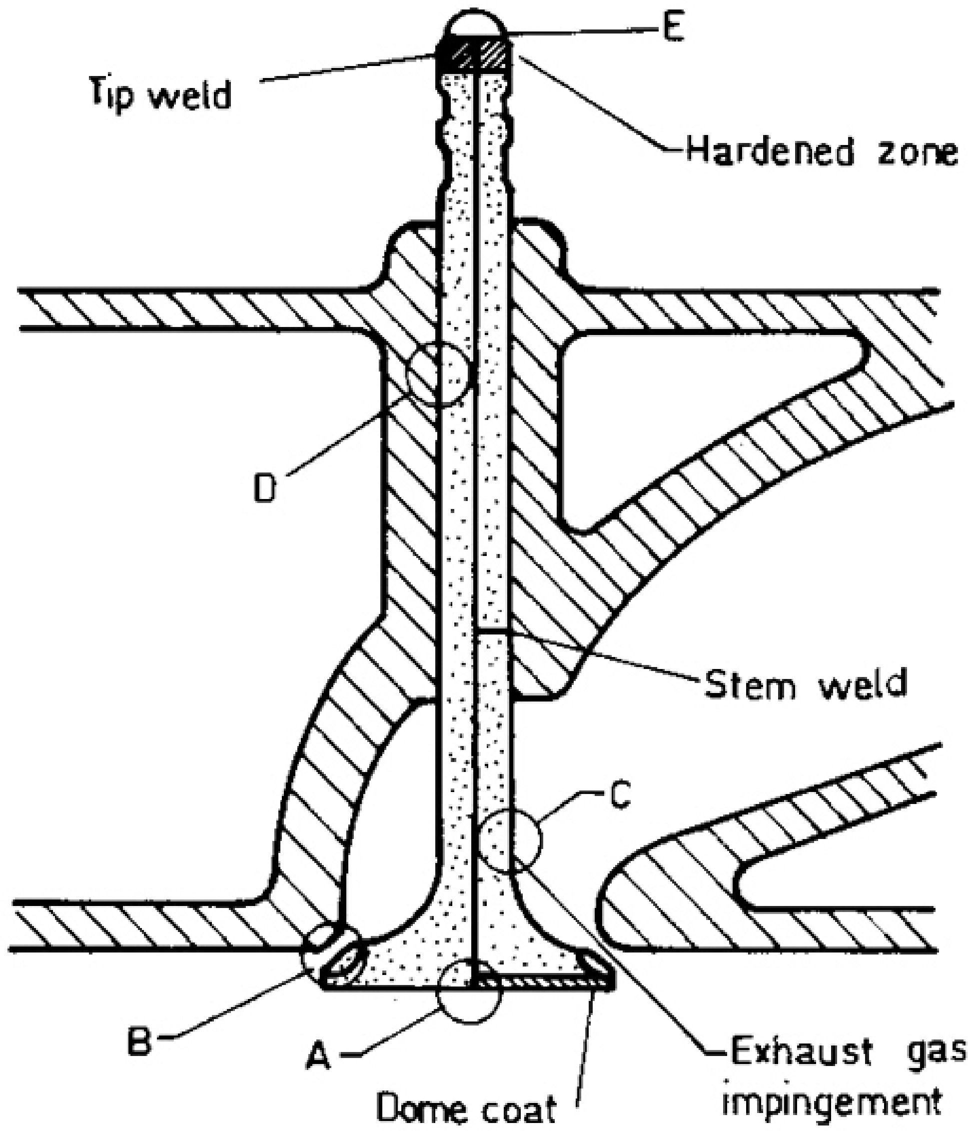


➤ The critical regions in an exhaust valve:



- Max. operating temp. occurs in **area A & C**, where corrosion and oxidation are critical.
- Under-head area (**area C**) experiences cyclic loading, and fatigue failure may occur at that point due to mild stress concentrations.
- Valve face (**area B**), operates at a somewhat lower temp. due to heat conduction into valve seat. However, if an insulating deposit builds up on valve face, it can lead to burning. Also, valve seat can be damaged by indentation of abrasive fuel ash deposits. Although valve stem is cooler then valve head, wear resistance is needed.
- Surface wear of valve stem (**area D**) can lead to scuffing (causes valve to stick open and burn).
- Wear at valve tip where the valve contacts rocker arm (**area E**) will cause the valve to seat with higher than the normal forces. Eventually, that will cause failure.

- The basic valve material for a passenger car application (where the max. temp. is 700 °C) is **an austenitic stainless steel (21-2N)** with good high-temp. properties.
- This alloy contains **20% chromium** to promote oxidation and corrosion resistance. It has good lead-oxide corrosion resistance, and its high temp. fatigue strength is exceeded only by that of more expensive nickel base super alloys.
- The entire body of one-piece valve is 21-2N, except for hard steel tip (**area E**) and hard chromium plate in **area D**. However, it is more economical to use **two-piece valve**, where 21-2N is replaced in the cooler stem portions by **cheaper alloy steel (SAE 3140 or SAE 4140)**.



- Two materials are joined by **friction welding**. Burning of valve face (**area B**) is generally avoided by **coating** valve surface with aluminum to produce Fe-Al alloy or, in severe cases, by hard facing the valve seat with one of Co-C-Cr-W Stellite alloys.