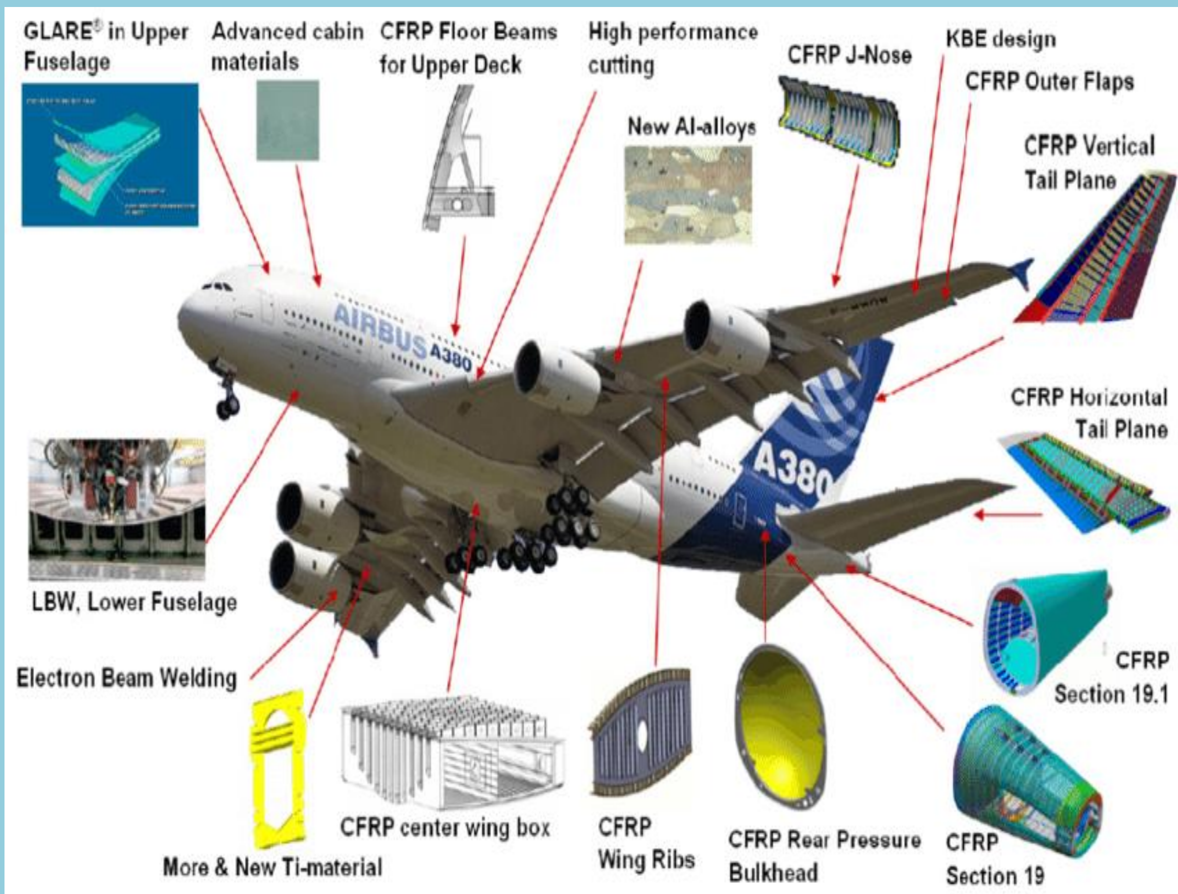
LECTURE-06: INTRODUCTION TO POWDER METALLURGY (PM)



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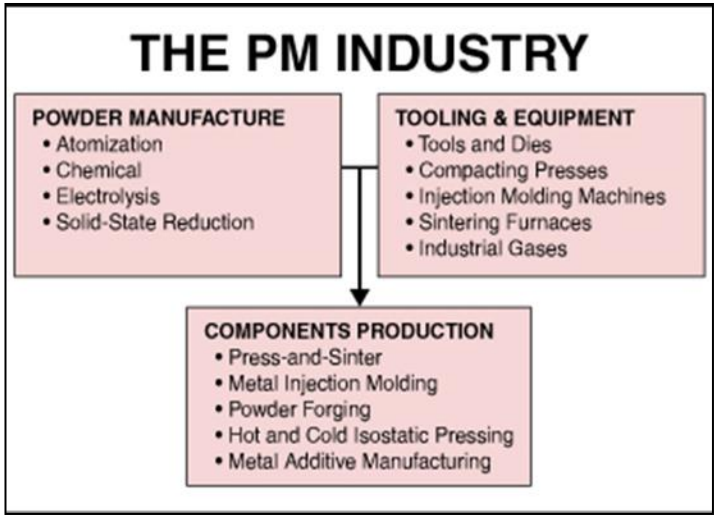
Introduction

- The powder metallurgy process, in which metal powders are compacted into desired and often complex shapes and sintered (heated without melting) to form a solid piece.
- Powder metallurgy has become competitive with processes such as casting, forging, and machining, particularly for relatively complex parts made of high strength and hard alloys.
- Most parts weigh less than 2.5 kg, they can weigh as much as 50 kg.
- The most commonly used metals in PM are iron, copper, aluminum, tin, nickel, titanium, and the refractory metals



Advantages of Powder Metallurgy

- Powder Metallurgy is a process for fabricating components by compacting finely powdered metallic or non metallic or both materials.
- It is solid state fabrication technique.
- Two or more metallic and/or non metallic powders are thoroughly blended together in a machine and then compacted at very high pressure using a die.
- The compacted powder will be still in the green state (to be handled carefully).
- The green compact is taken out of the die and sintered at very high temperature to get a hardened mass having the desired configuration with enhanced strength and other mechanical properties.

Parts Made by Powder-Metallurgy

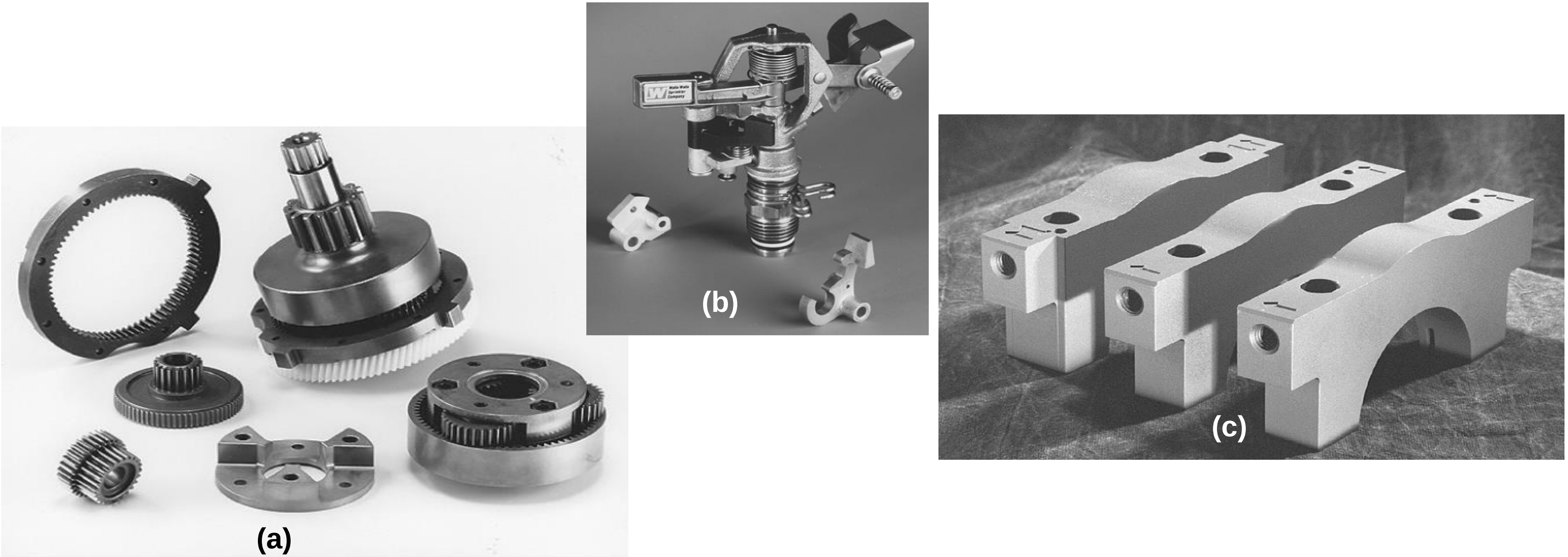


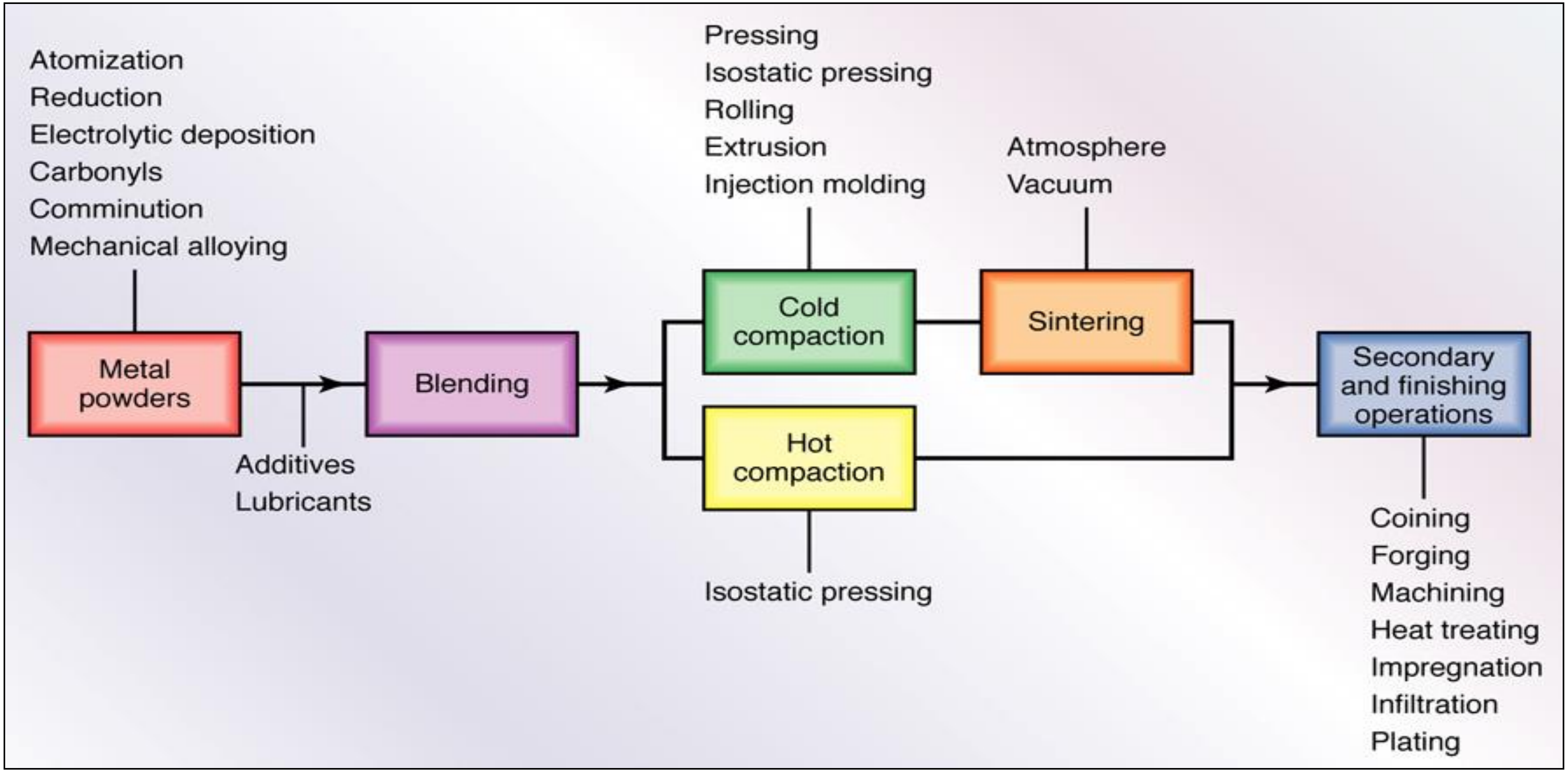
Figure (a) Examples of typical parts made by powder-metallurgy processes. (b) Upper trip lever for a commercial sprinkler made by P/M. This part is made of an unleaded brass alloy; it replaces a die-cast part with a 60% savings. (c) Main-bearing metal-powder caps for 3.8 and 3.1 liter General Motors automotive engines

Production of Metal Powders

The powder-metallurgy process consists of the following operations, in sequence :

- Powder production
- Blending
- Compaction
- Sintering
- Finishing operation

Steps in Making Powder-Metallurgy Parts

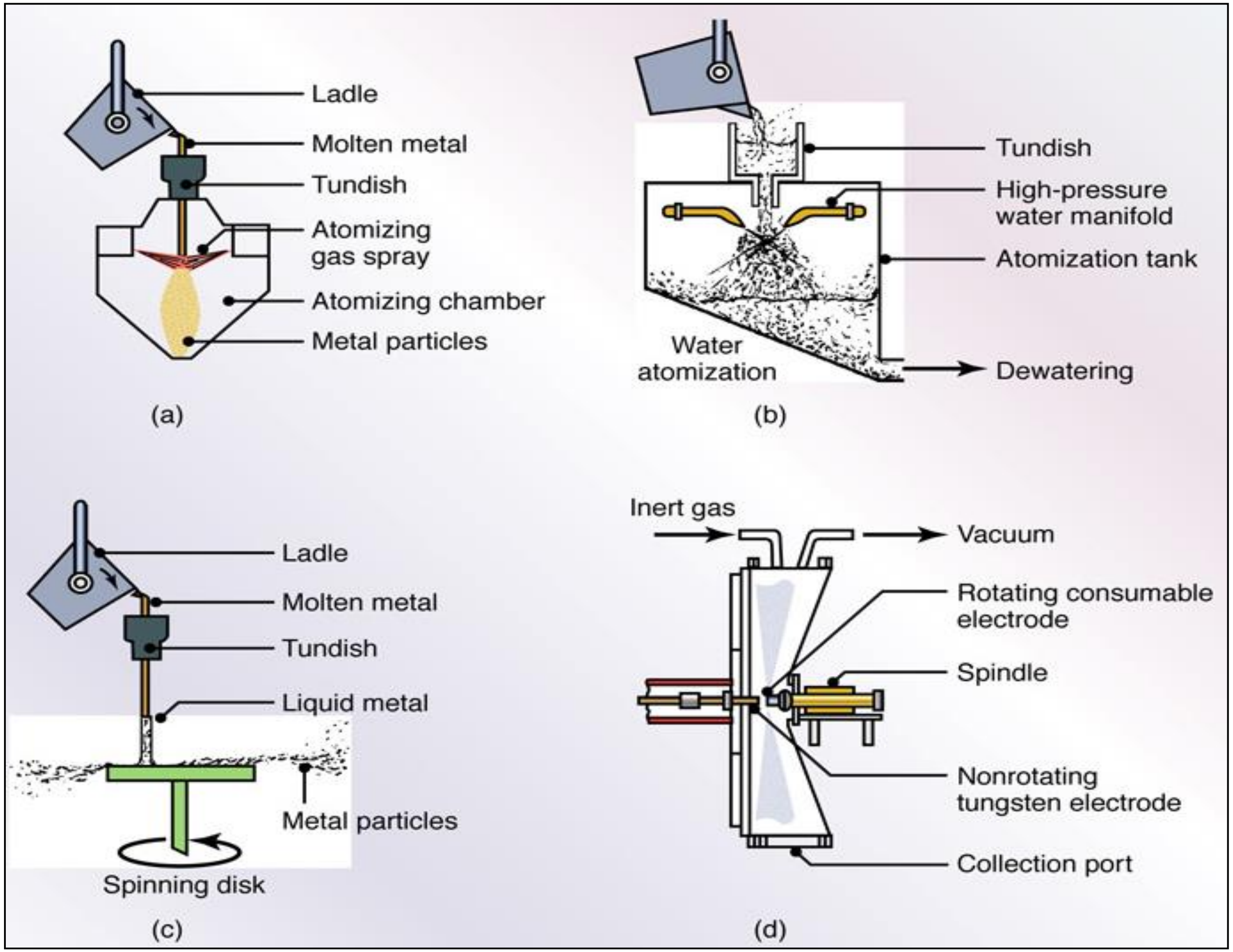


Outline of processes and operations involved in making powder-metallurgy parts.

Methods of Powder Production

Atomization

- Atomization produces a liquid-metal stream by injection molten metal through a small orifice.
- The stream is broken by jets of inert gas or air → gas atomization (Fig. a), or water → water atomization (Fig. b).
- The size and shape of the particles formed depends on the temperature of the molten metal, rate of flow, nozzle size, and jet characteristics.
- Use of water results in slurry of metal powder and liquid at the bottom of the atomization chamber. Although the powders must be dried before they can be used, the water allows for rapid cooling of the particles and higher production rates.
- Gas atomization usually results in more spherical particles (Fig. c).
- In centrifugal atomization, the molten-metal stream drops onto a rapid rotating disk or cup, so that centrifugal forces break up the molten-metal stream and generate particles (Fig. c).



Methods of metal-powder production by atomization:

(a) gas atomization; (b) water atomization; (c) atomization with a rotating consumable electrode; and (d) centrifugal atomization with a spinning disk or cup.

Reduction

- The reduction of metal oxides (i.e., removal of oxygen) uses gases, such as hydrogen and carbon monoxide, as reducing agents.
- Very fine metallic oxides are reduced to the metallic state.
- Powders produced are spongy and porous and have uniformly sized spherical or angular shapes.

Electrolytic Deposition

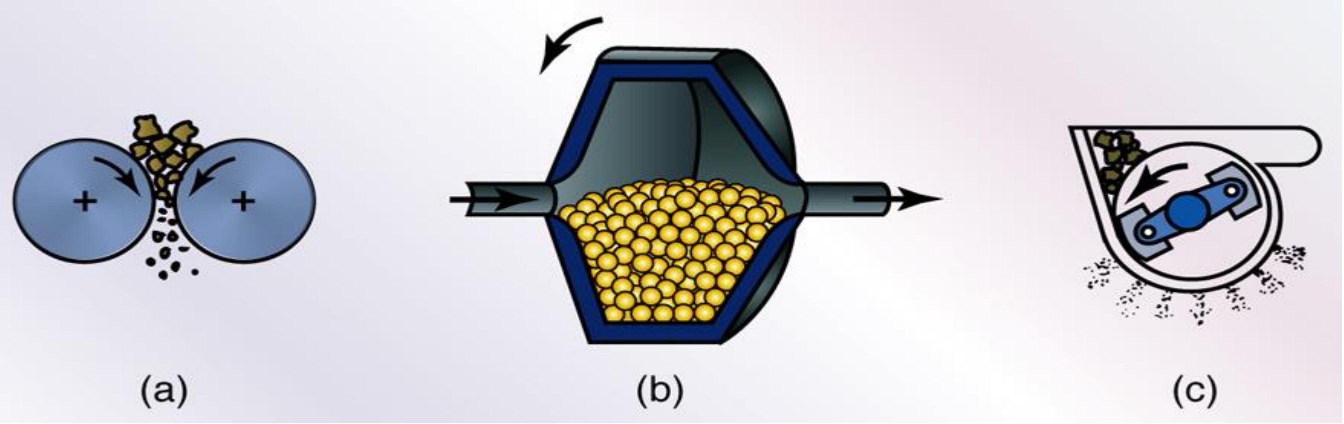
- Utilizes either aqueous solution or fused salts.
- The powders produced are among the purest available.

Carbonyls

- Metal carbonyls, such as iron carbonyl [Fe(CO)5] and nickel carbonyl [Ni(CO)4], are formed by letting iron or nickel react with carbon monoxide.
- The reaction products are then decomposed to iron and nickel, and they turn into small, dense, uniformly spherical particles of high purity.

Pulverization

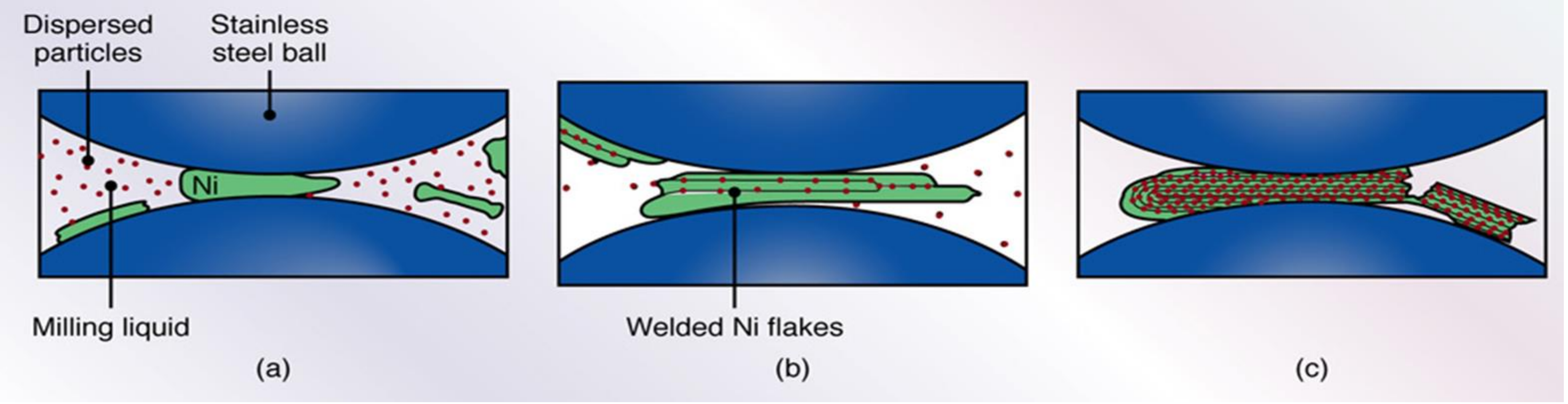
- Mechanical pulverization involves crushing (Fig.), milling in a ball mill, or grinding of brittle or less ductile metals into small particles.
- A ball mill (Fig. b) is a machine with a rotating hollow cylinder partly filled with steel or white cast-iron balls.
- For brittle materials, the powder particles produced have angular shapes.
- For ductile materials, particles are flaky and not suitable for P/M applications



Methods of mechanical comminution to obtain fine particles: (a) roll crushing, (b) ball mill, and (c) hammer milling.

Mechanical Alloying

- Powders of two or more metals are mixed in a ball mill (Figure).
- Under the impact of hard balls, the powders fracture and bond together by diffusion, forming alloy powders.
- The dispersed phase can result in strengthening of the particles or can impart special electrical or magnetic properties of the powder.



Mechanical alloying of nickel particles with dispersed smaller particles. As nickel particles are flattened between the two balls, the second smaller phase is impresses into the nickel surface and eventually is dispersed throughout the particle due to successive flattening, fracture, and welding events.

Particle Size, Shape and Distribution

- Particle size is usually measured by screening – by passing the metal powder through sieves of various mesh sizes.
- Screen analysis is achieved by using a vertical stack of screens with the mesh size becoming fine as the powder flows downward through the screens. The larger the mesh size, the smaller is the opening in the screen. For example, a mesh size of 30 has an opening of 600 μm, size of 100 has 150 μm, and size 400 has 38 μm.
- In addition to screen (sieve) analysis, several other methods are available for particle-size analysis:
- Sedimentation, which involves measuring the rate at which particles settle in a fluid.
- Microscopic analysis, which may include the use of transmission and scanning electron microscopy.
- Light scattering from a laser that illuminates a sample consisting of particles suspended in a liquid medium. The particles cause the light to be

Particle Size, Shape and Distribution

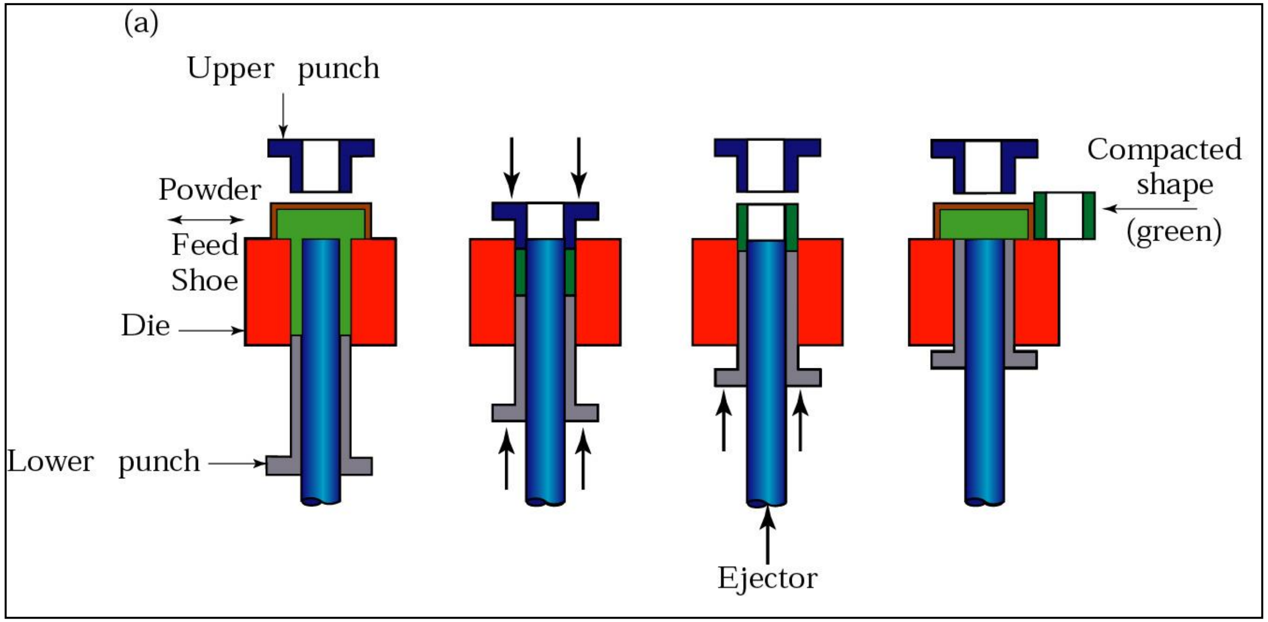
- Particle Shape: Particle shape is usually described in terms of aspect ratio.
  - Aspect ratio is the ratio of the largest dimension to the smallest dimension of the particle.
  - The ratio ranges from unity (spherical particles) to about 10 for flake-like or needle-like particles.
- Shape Factor
  - Shape factor (shape index) is a measure of the ratio of the surface area of the particle to its volume – normalized by reference to a spherical particle of equivalent volume.
  - Thus, the shape factor for a flake is higher than that for a sphere.
- Size Distribution
  - It is an important consideration because it affects the processing characteristics of the powder.
  - The distribution of a particle is given in terms of frequency-distribution. The maximum is called the mode size.

Blending Metal Powders

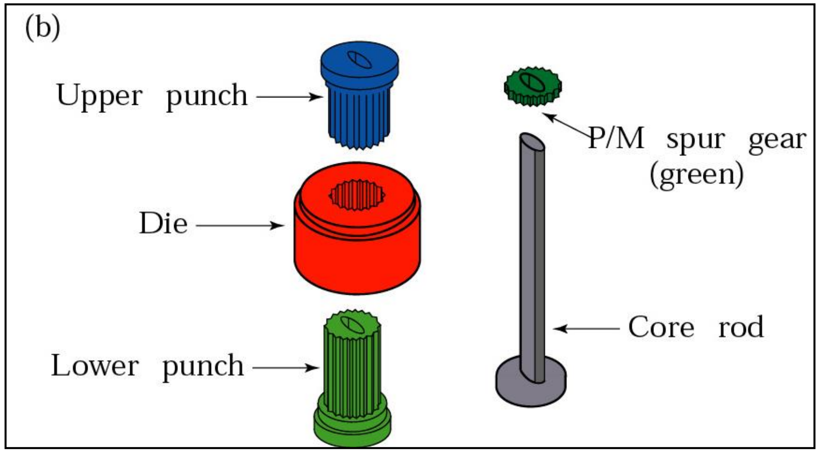
- Proper mixing is essential to ensure uniformity of mechanical properties throughout the part
- Powders of different metals can be mixed to impart special physical and mechanical properties to the P/M product.
- Lubricants can be mixed with the powders to improve their flow characteristics. They reduce friction between metal particles, improve flow of the powder metals into the die, and improve die life. Lubricants are typically stearic acids or zinc stearate in a proportion from 0.25% - 5% by weight.
- Other additives – binders are used to develop sufficient green strength, and additives also can be used to facilitate sintering.
- Powders can be mixed in air, in inert atmosphere (to avoid oxidization), or in liquids (which act as lubricants and make the mix more uniform).
- Several types of blending equipment are available.

Compaction of Metal Powders

- In this step blended powders are pressed into various shapes in dies.
- Purposes of compaction are to obtain the required shape, density, and particle-to-particle contact and to make part sufficiently strong for further processes.
- Figure in the next slide shows a sequence of steps. The powder (feedstock) is feed into the die by a feed show; the upper punch descends into the die (single or double punches). The lower punch raises the part out of the dies.
- The presses used are actuated either hydraulically or mechanically.
- The process is carried out at room temperature, although it can be done at elevated temperature.



(a) Compaction of metal powder to form a bushing. The pressed-powder part is called green compact.

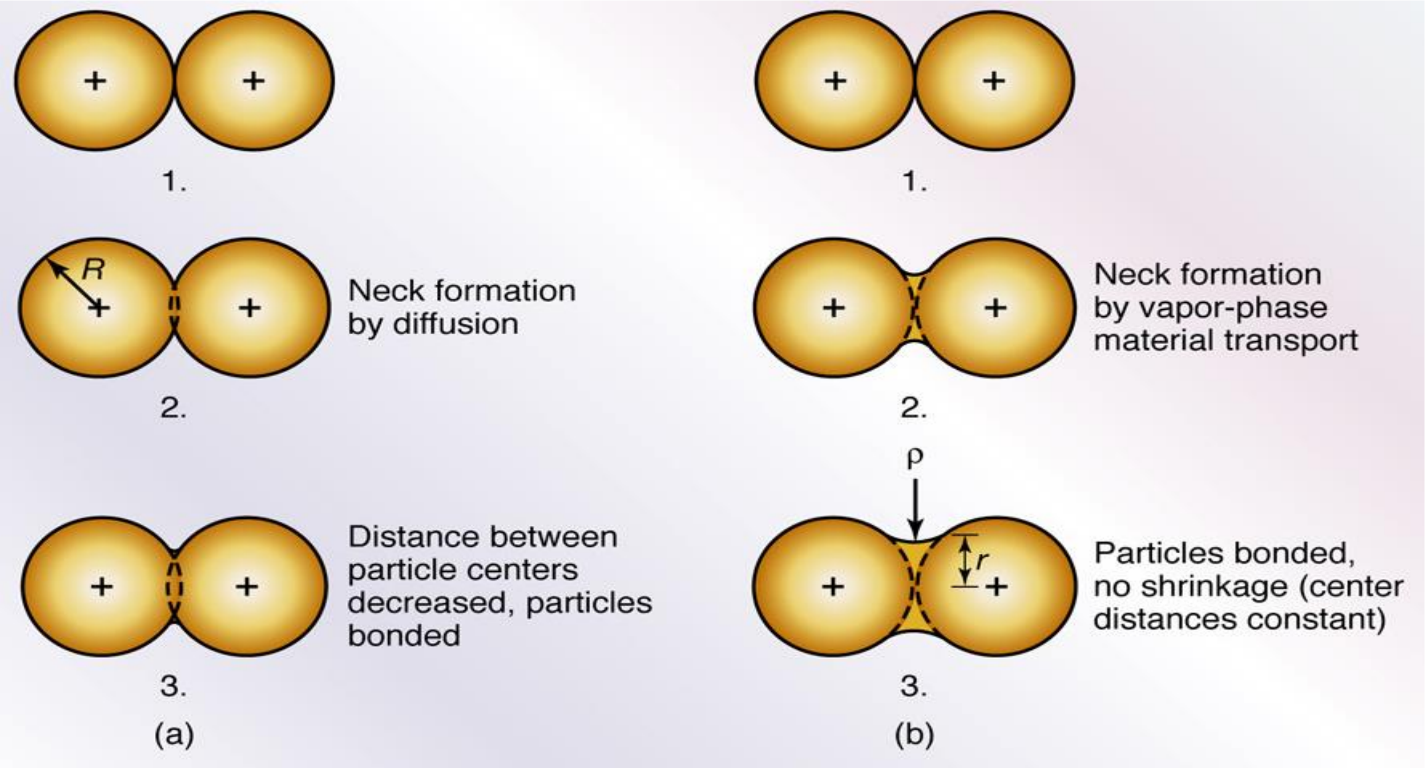


(b) Typical tool and die set for compacting a spur gear.

Sintering Metal Powders

- In the **sintering operation**, the pressed-powder compacts are **heated** in a controlled atmosphere to **right below the melting point**
- Three stages of sintering
  - **Burn-off (purge)**- combusts any air and removes lubricants or binders that would interfere with good bonding
  - **High-temperature**- desired solid-state diffusion and bonding occurs
  - **Cooling period**- lowers the temperature of the products in a controlled atmosphere
- All **three stages** must be conducted in **oxygen-free conditions** of a vacuum or protective atmosphere.

Mechanisms for Sintering Metal Powders



Schematic illustration of two mechanisms for sintering metal powders: (a) solid-state material transport; and (b) vapor-phase material transport. *R* = particle radius, *r* = neck radius, and *p* = neck-profile radius.