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POWDER METALLURGY

Dr. M. Sayuti, ST.,M.Sc

JURUSAN TEKNIK INDUSTRI

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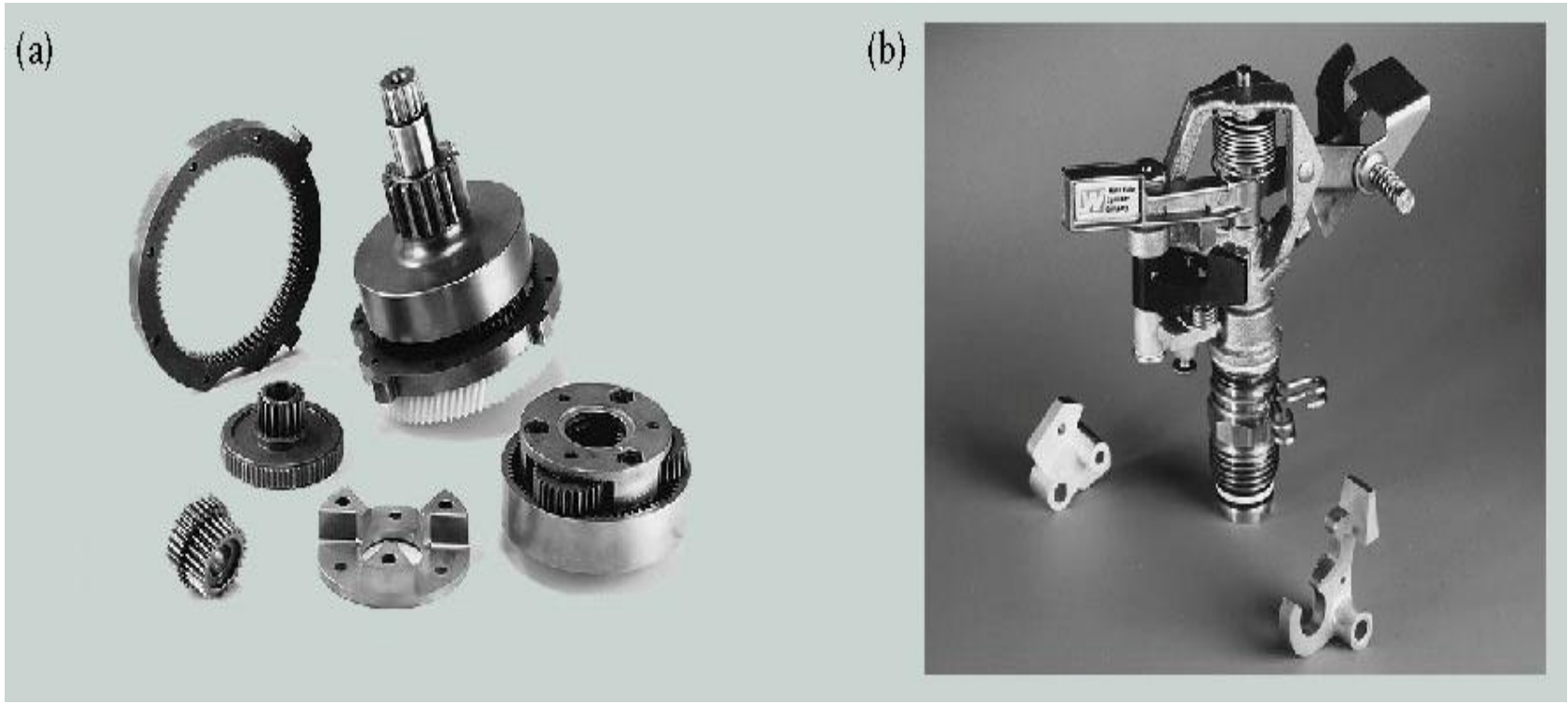
1- INTRODUCTION

- Powder metallurgy is the name given to the process by which fine powdered materials are blended, pressed into a desired shape, and then heated to bond surfaces
- Typically used when large amounts of small, intricate parts with high precision are required
- Little material waste and unusual mixtures can be utilized
- Used for parts in the automotive industry, household appliances, and recreational equipment (to name a few)

Advantages and Disadvantages of Powder Metallurgy

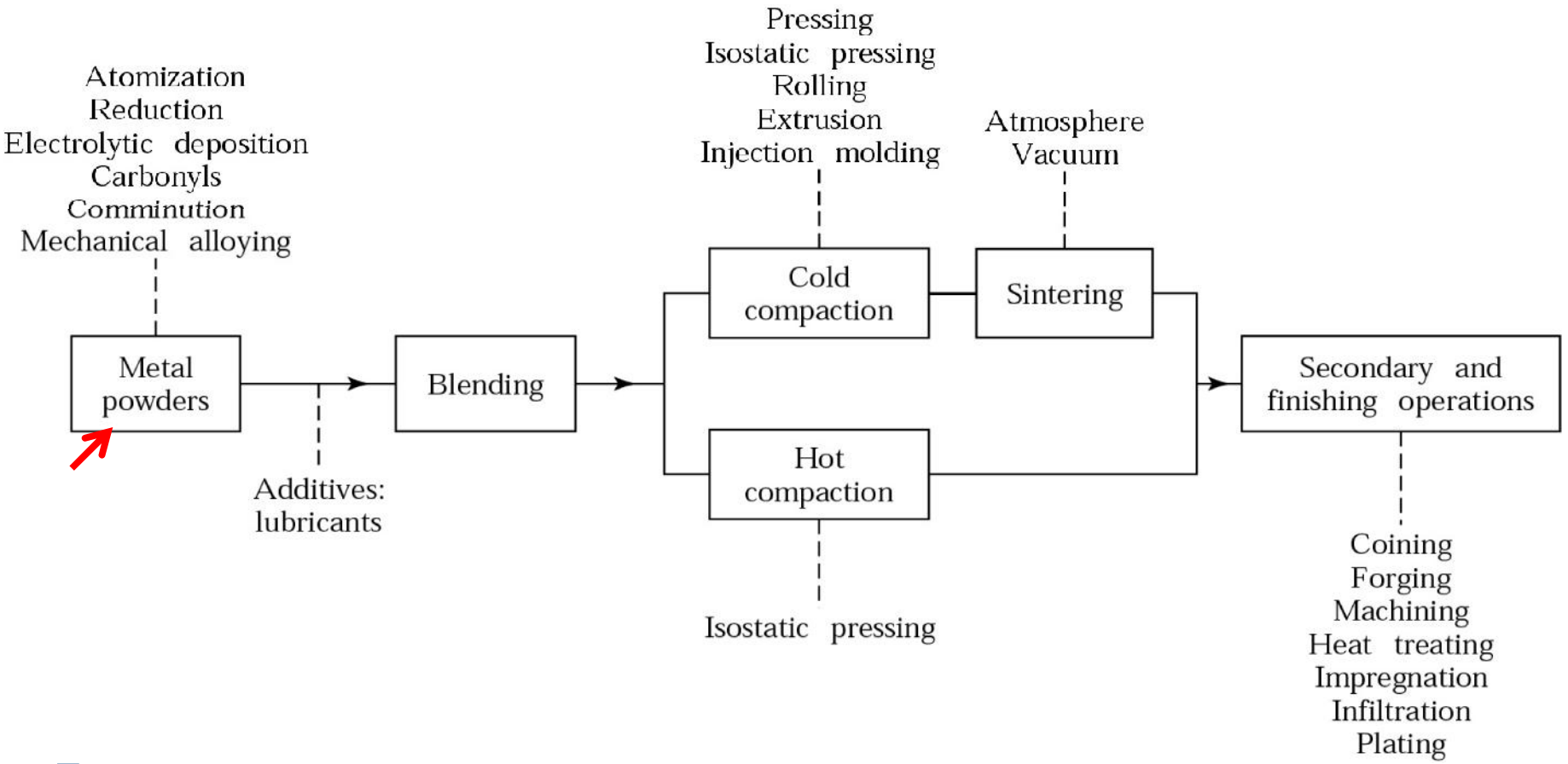
- Advantages
  - Elimination or reduction of machining
  - High production rates
  - Complex shapes
  - Wide variations in compositions
  - Wide property variations
  - Scrap is eliminated or reduced
  - High strength parts with low ductility metals
  - Good microstructure control
  - High tolerance parts possible with minimum processing
- Disadvantages
  - Inferior strength properties
  - High tooling costs
  - High material cost
  - Size and shape limitations
  - Dimensional changes during sintering
  - Density variations
  - Health and safety hazards
  - Porosity and low ductility may impair durability.
  - Fracture Toughness may be low.
  - Strength and stiffness may be inferior to wrought alloys of similar composition.

2. POWDER-METALLURGY PROCESSES



- Upper trip lever for a commercial irrigation sprinkler, made by P/M. this part is made of unleaded brass alloy; it replaces a die-cast part, with a 60% savings.
- Examples of typical parts made by powder-metallurgy processes.

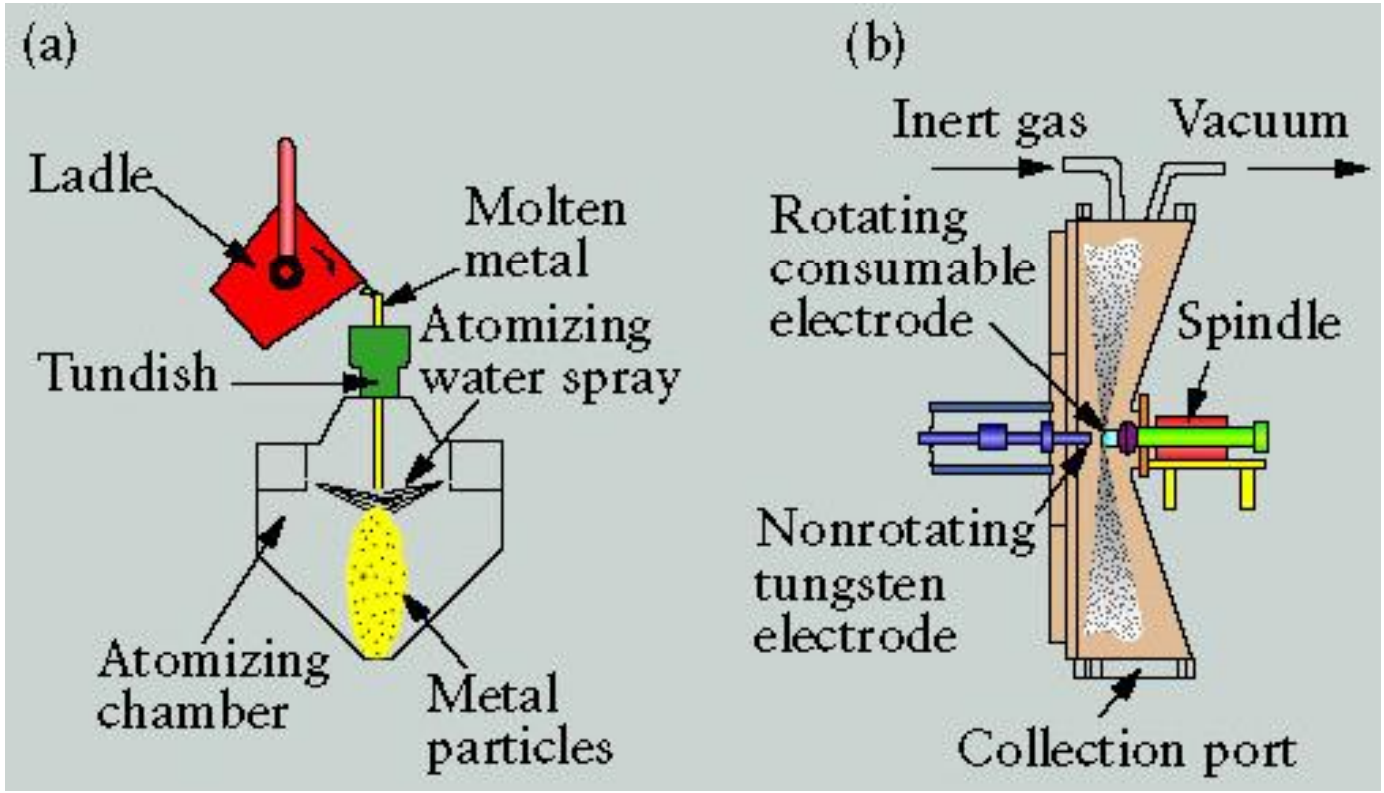
Making Powder-Metallurgy Parts



3. POWDER MANUFACTURE

- Properties of powder metallurgy products are highly dependent on the characteristics of starting powders
- Some important properties and characteristics
  - Chemistry and purity
  - Particle size
  - Size distribution
  - Particle shape
  - Surface texture
- Useful in producing prealloyed powders
  - Each powder particle can have the desired alloy composition
- The majority of commercial powder is produced by some form of melt atomization
  - Atomization is a process where liquid metal is fragmented into small droplets that cool and solidify into particles

Methods of metal-powder production by atomization

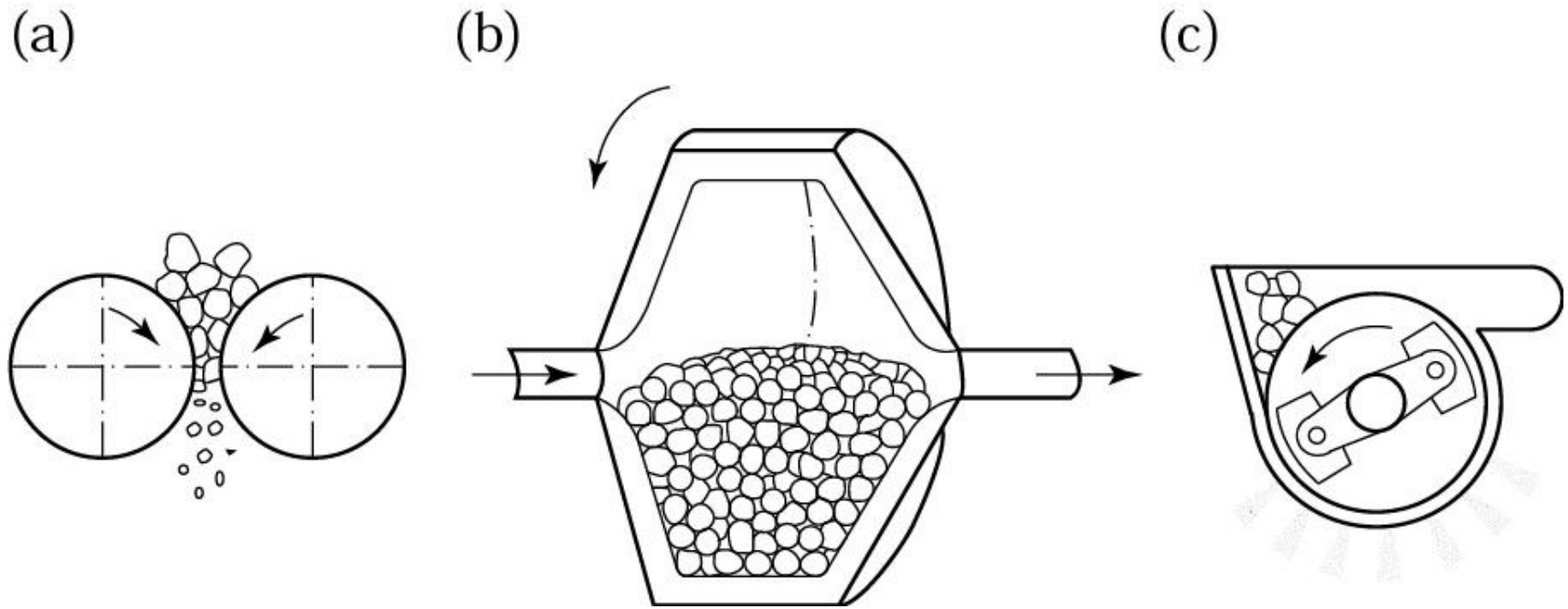


- (a) melt atomization
- (b) atomization with a rotating consumable electrode.

Additional Methods of Powder Manufacture

- Methods
  - Chemical reduction of particulate compounds
  - Electrolytic deposition
  - Pulverization or grinding
  - Thermal decomposition of particulate hydrides
  - Precipitation from solution
  - Condensation of metal vapors
- Almost any metal or alloy can be converted into powder

Mechanical Comminution/pulverization

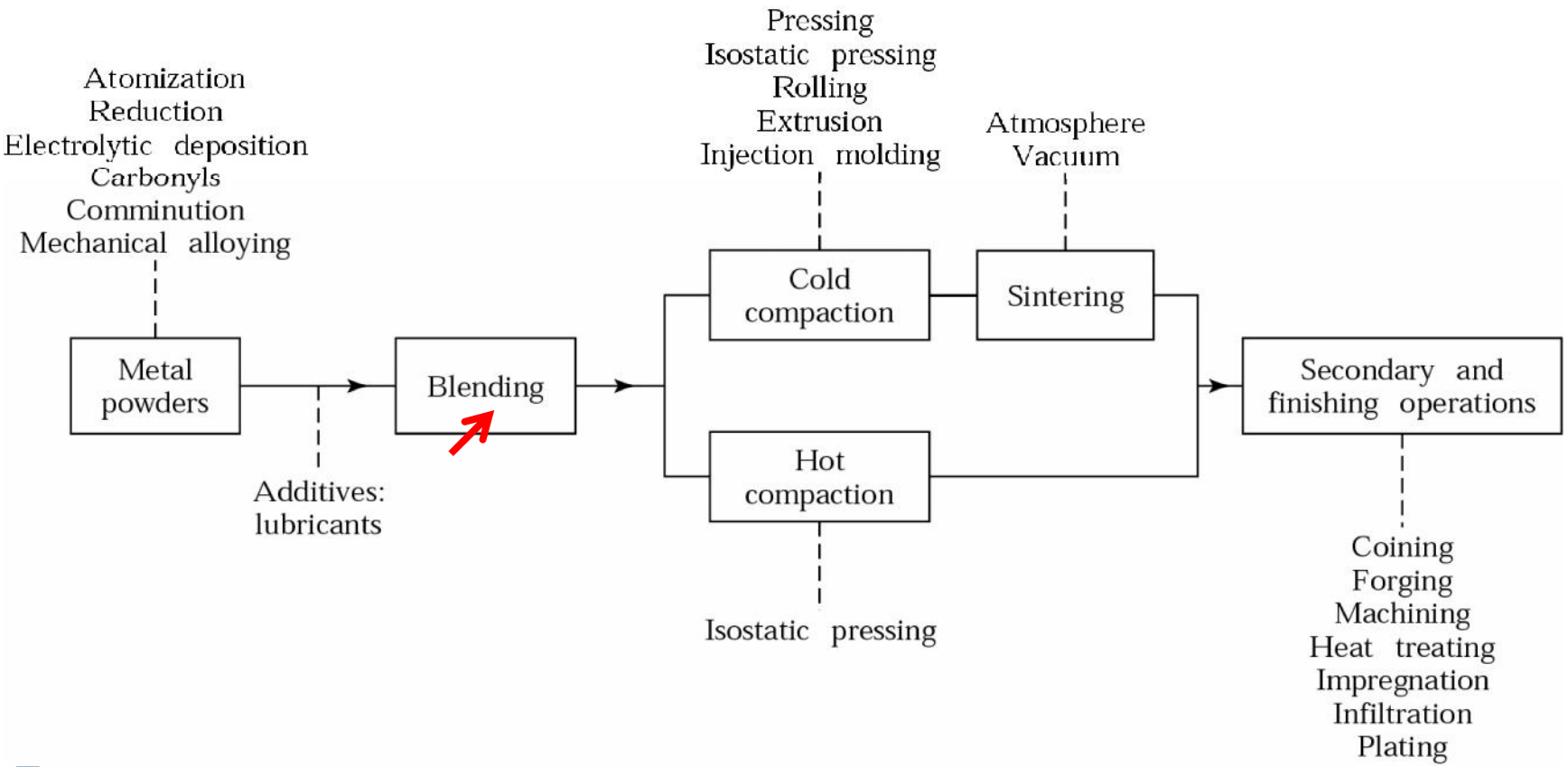


- (a) roll crushing, (b) ball mill, and (c) hammer milling.

4- POWDER TESTING AND EVALUATION

- Powders should be evaluated for their suitability for further processing
- *Flow rate* measures the ease with which powder can be fed and distributed into a die
- *Apparent density* is the measure of a powder's ability to fill available space without external pressure
- *Compressibility* is the effectiveness of applied pressure
- *Green strength* is used to describe the strength of the pressed powder after compacting

Making Powder-Metallurgy Parts



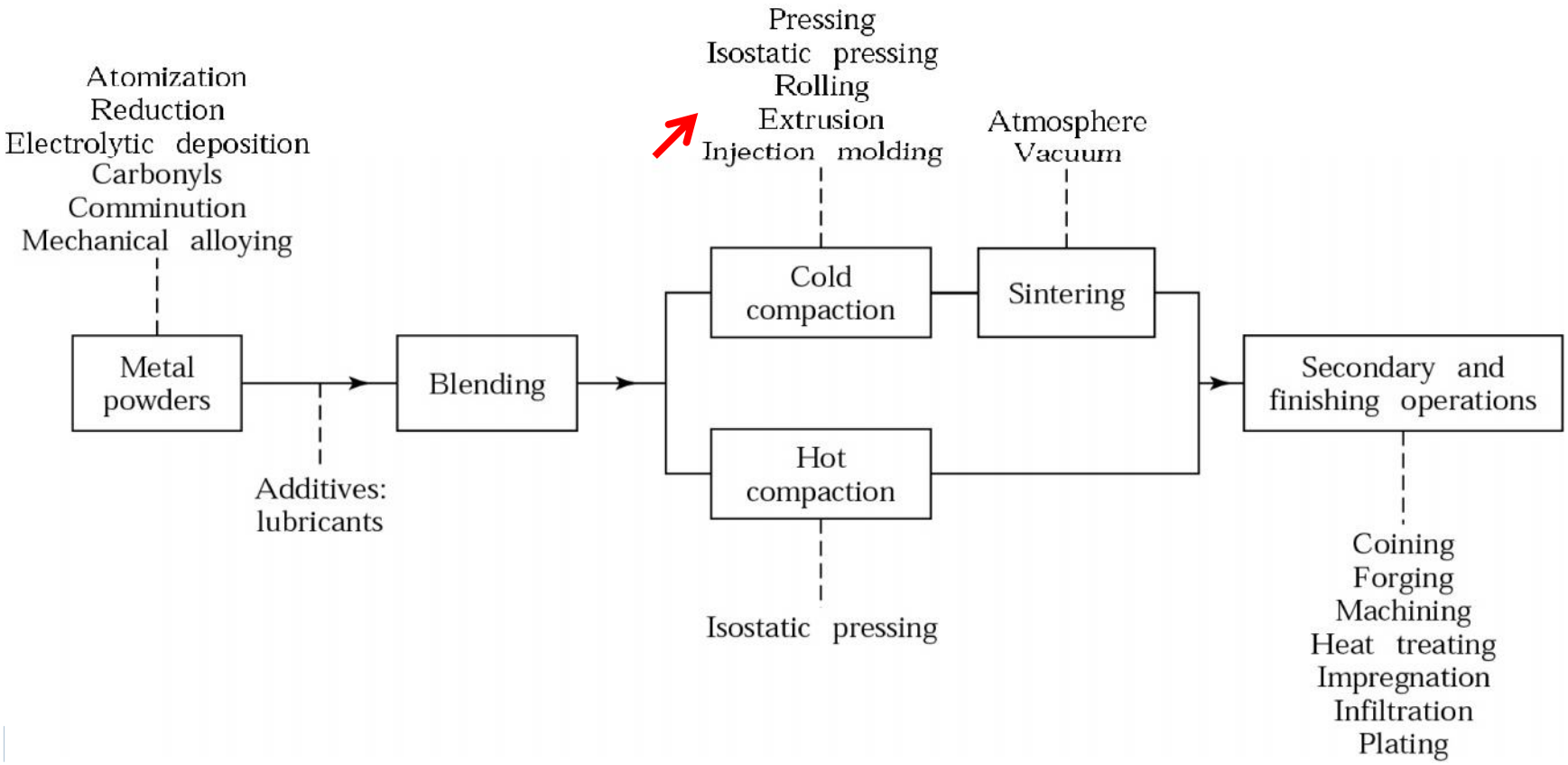
5- POWDER MIXING AND BLENDING

- The majority of powders are mixed with other powders, binders, and lubricants to achieve the desired characteristics in the finished product
- Sufficient diffusion must occur during sintering to ensure a uniform chemistry and structure
- Unique composites can be produced
- Blending or mixing operations can be done either wet or dry

Blending metal powders

- Mix to obtain uniformity
- Mix to obtain desired physical and mechanical properties
- Mix lubricants to improve flow characteristics
- Blend in air, inert(to avoid oxidation) or in liquids

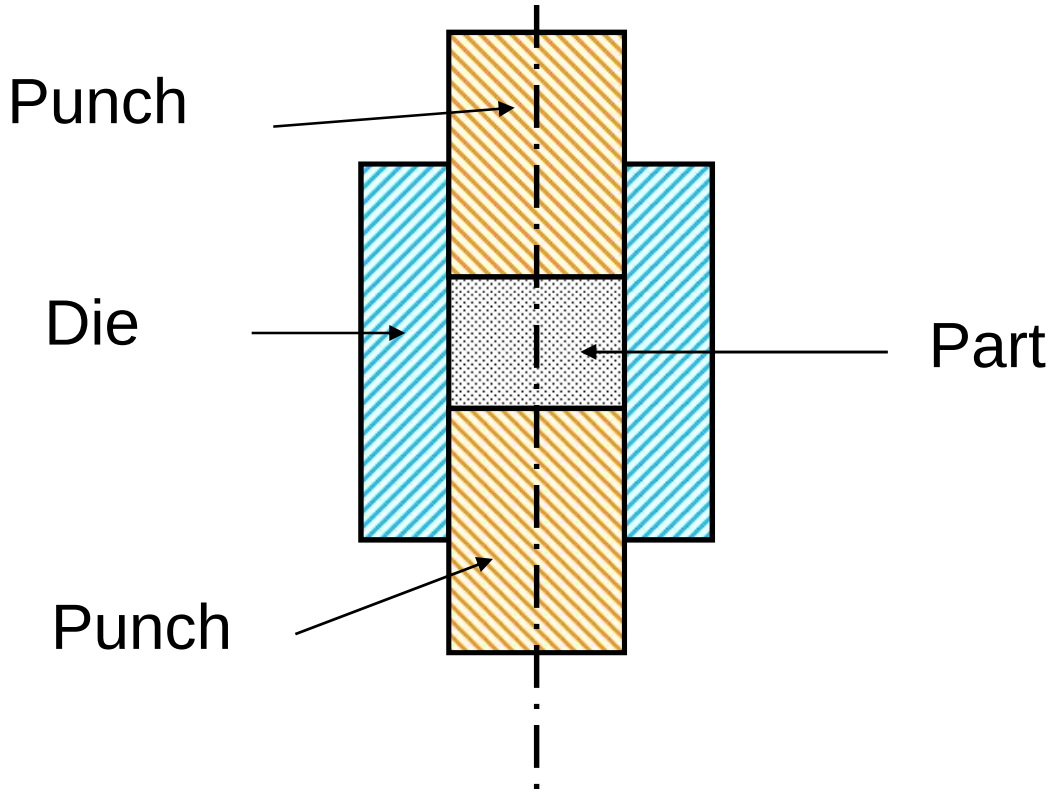
Making Powder-Metallurgy Parts



Powder Processing

- Cold compaction and sintering
  - Pressing
  - Rolling
  - Extrusion
  - Injection molding
  - Isostatic pressing
- Hot Isostatic Pressing

Powder Pressing



Dual action press

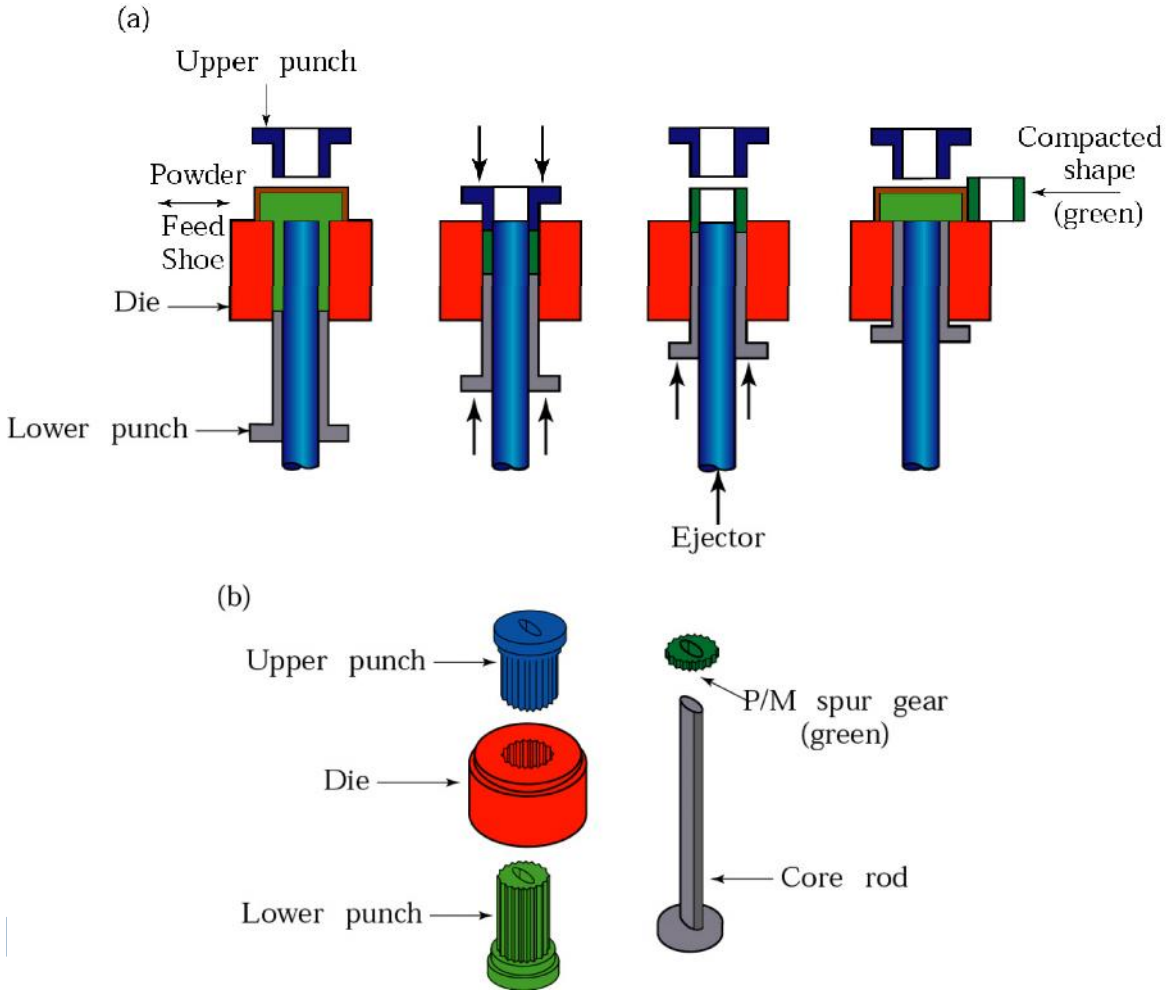
6- COMPACTING

- Loose powder is compacted and densified into a shape, known as green compact
- Most compacting is done with mechanical presses and rigid tools
  - Hydraulic and pneumatic presses are also used

TABLE 18-1 Typical Compacting Pressures for Various Applications

Application	Compaction Pressures tons/in.^{2}	Mpa
Porous metals and filters	3–5	40–70
Refractory metals and carbides	5–15	70–200
Porous bearings	10–25	146–350
Machine parts (medium-density iron & steel)	20–50	275–690
High-density copper and aluminum parts	18–20	250–275
High-density iron and steel parts	50–120	690–1650

Compaction

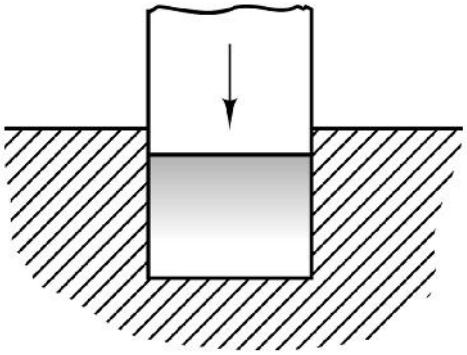


(a) Compaction of metal powder to form a bushing. The pressed powder part is called green compact.

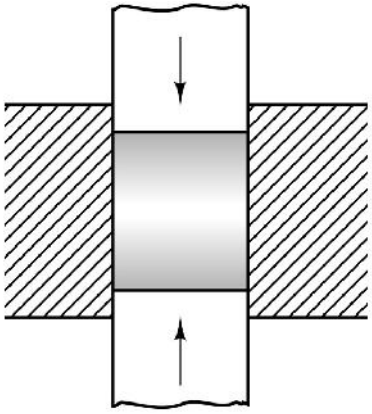
(b) Typical tool and die set for compacting a spur gear.

Additional Considerations During Compacting

- When the pressure is applied by only one punch, the maximum density occurs right below the punch surface and decreases away from the punch
- For complex shapes, multiple punches should be used

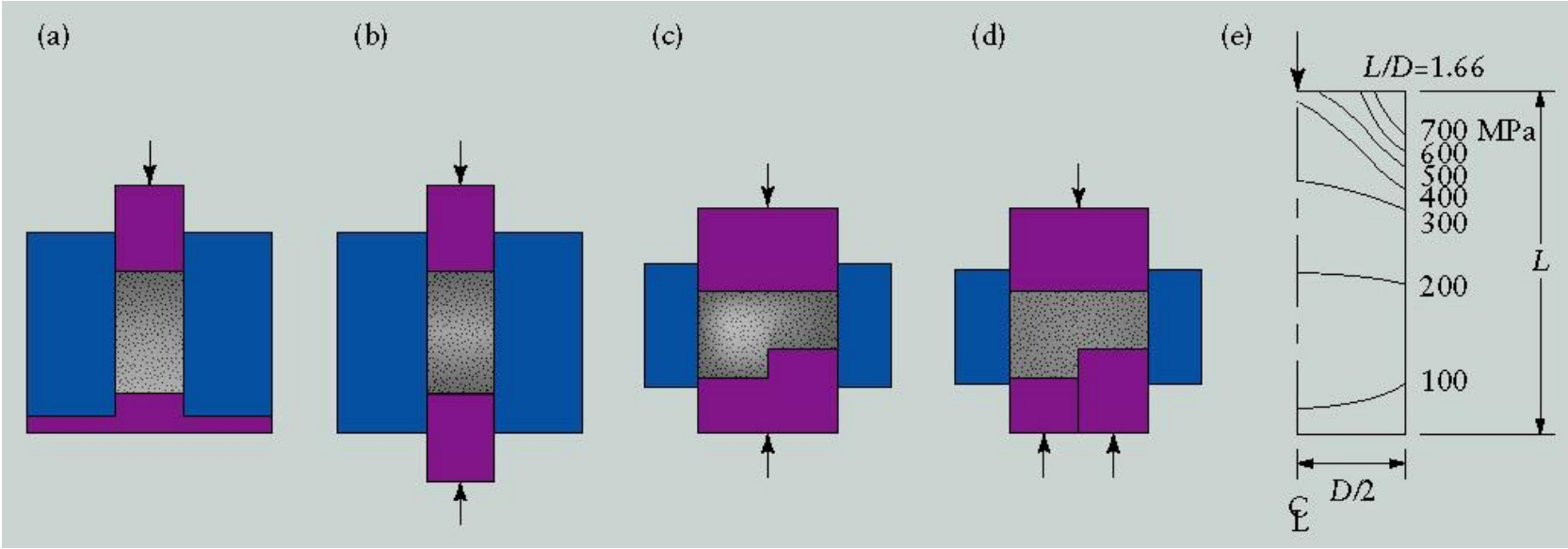


Compaction with a single moving punch, showing the resultant nonuniform density (shaded), highest where particle movement is the greatest.



Density distribution obtained with a double-acting press and two moving punches. Note the increased uniformity compared to Figure 18-5. Thicker parts can be effectively compacted.

Density Variation



Density variation in compacting metal powders in different dies:

(a) and (c) single-action press

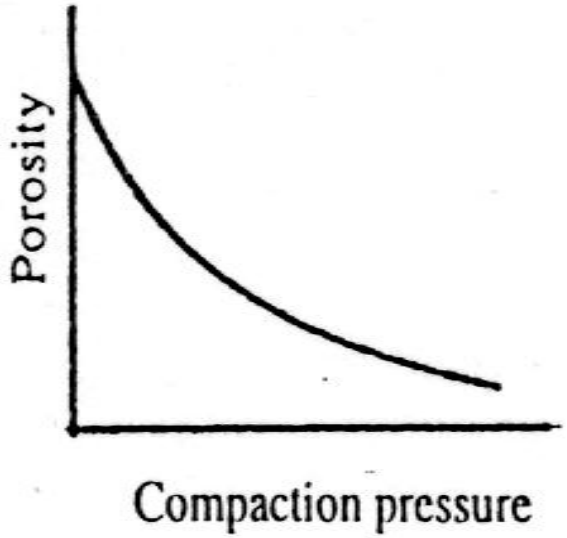
(b) and (d) double-action press.

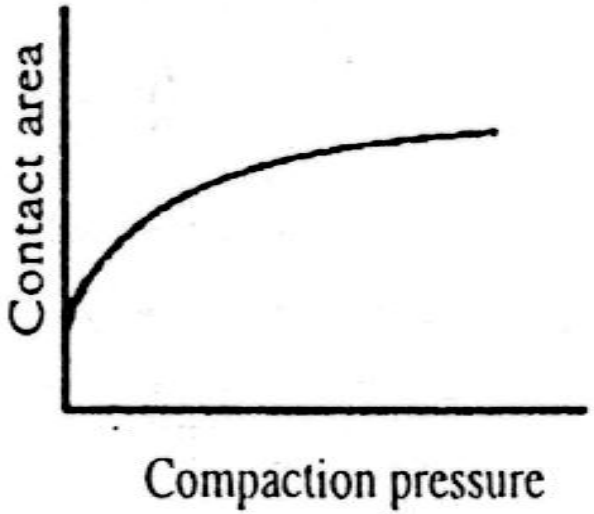
Note in (d) the greater uniformity of density in pressing with two punches with separate movements as compared with (c).

Generally, uniformity of density is preferred, although there are situations in which density variation, and hence variation of properties, within a apart may be desirable.

Relation

(*compaction pressure vs. porosity ,contact area*)



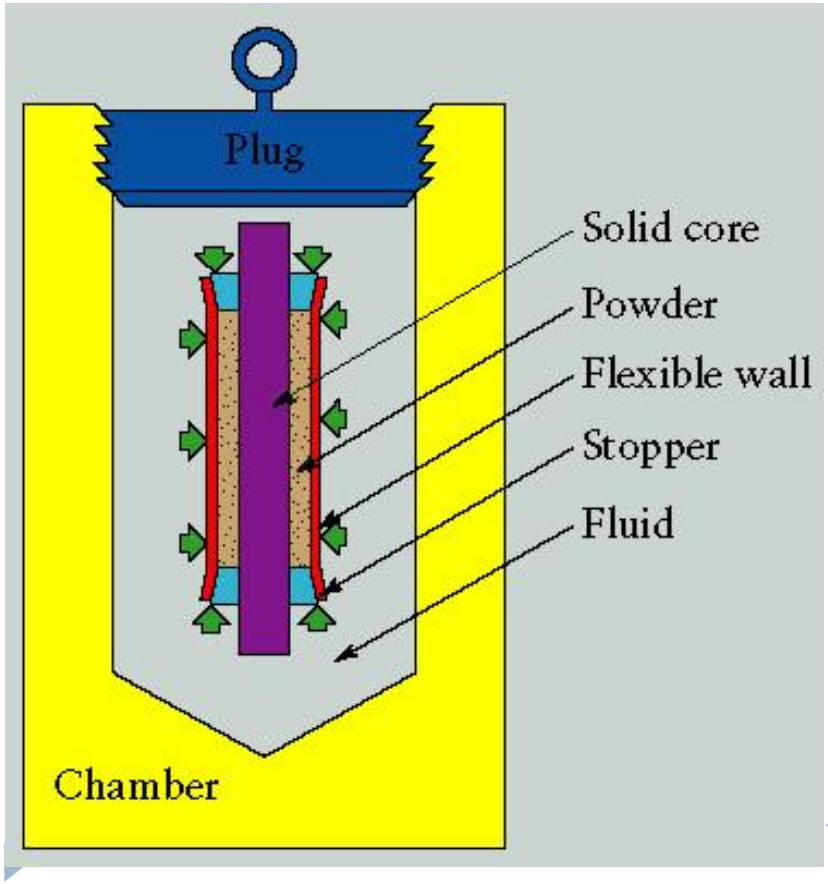


- Increased compaction pressure
  - Provides better packing of particles and leads to ↓ porosity
  - ↑ localized deformation allowing new contacts to be formed between particles

Complex Compacting

- If an extremely complex shape is desired, the powder may be encapsulated in a flexible mold, which is then immersed in a pressurized gas or liquid
  - Process is known as isostatic compaction
- In warm compaction, the powder is heated prior to pressing
- The amount of lubricant can be increased in the powder to reduce friction
- Because particles tend to be abrasive, tool wear is a concern in powder forming

7-COLD ISOSTATIC PRESSING (CIP)

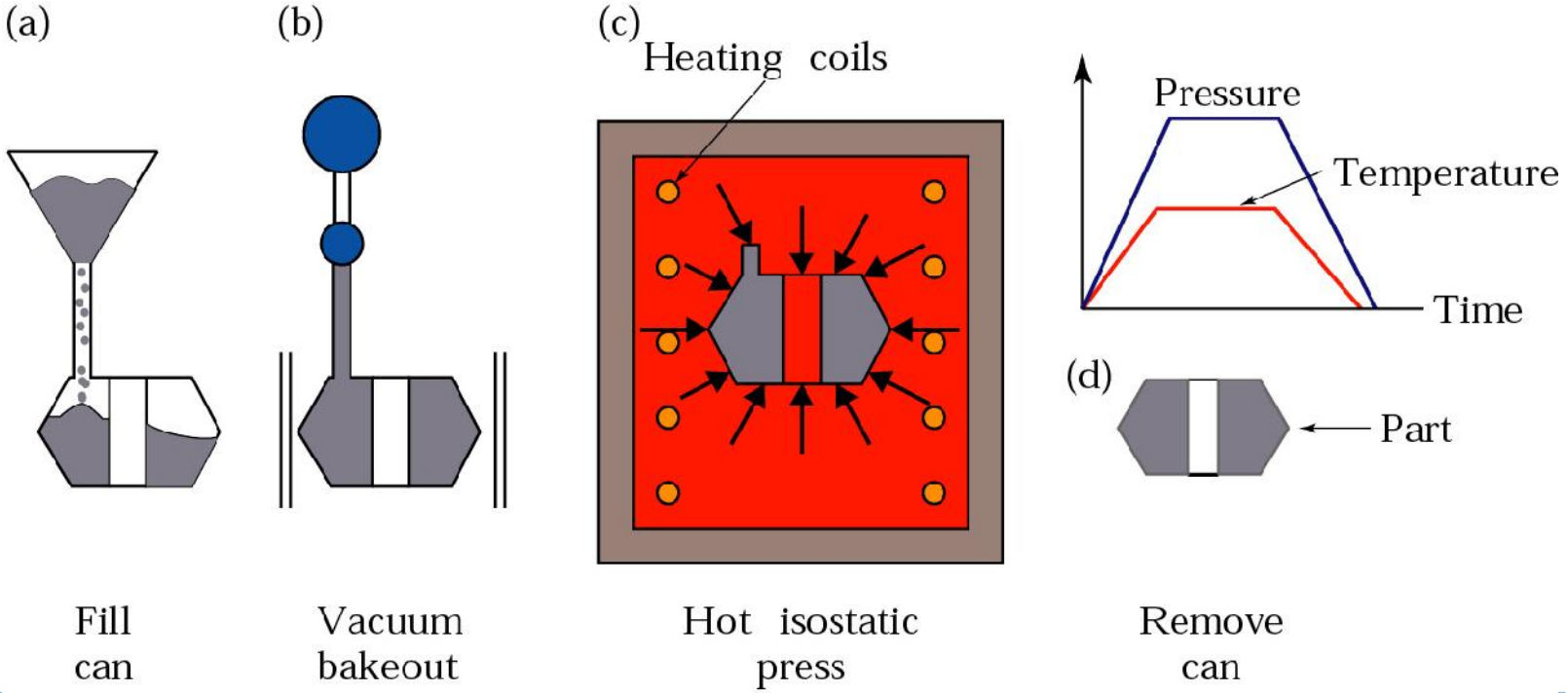


- Schematic illustration of cold isostatic pressing as applied to formation of a tube. The powder is enclosed in a flexible container around a solid core rod. Pressure is applied isostatically to the assembly inside a high-pressure chamber.

Hot-Isostatic Pressing

- Hot-isostatic pressing (HIP) combines powder compaction and sintering into a single operation
  - Gas-pressure squeezing at high temperatures
- Heated powders may need to be protected from harmful environments
- Products emerge at full density with unifrom, isotropic properties
- Near-net shapes are possible

Hot Isostatic Pressing(HIP)



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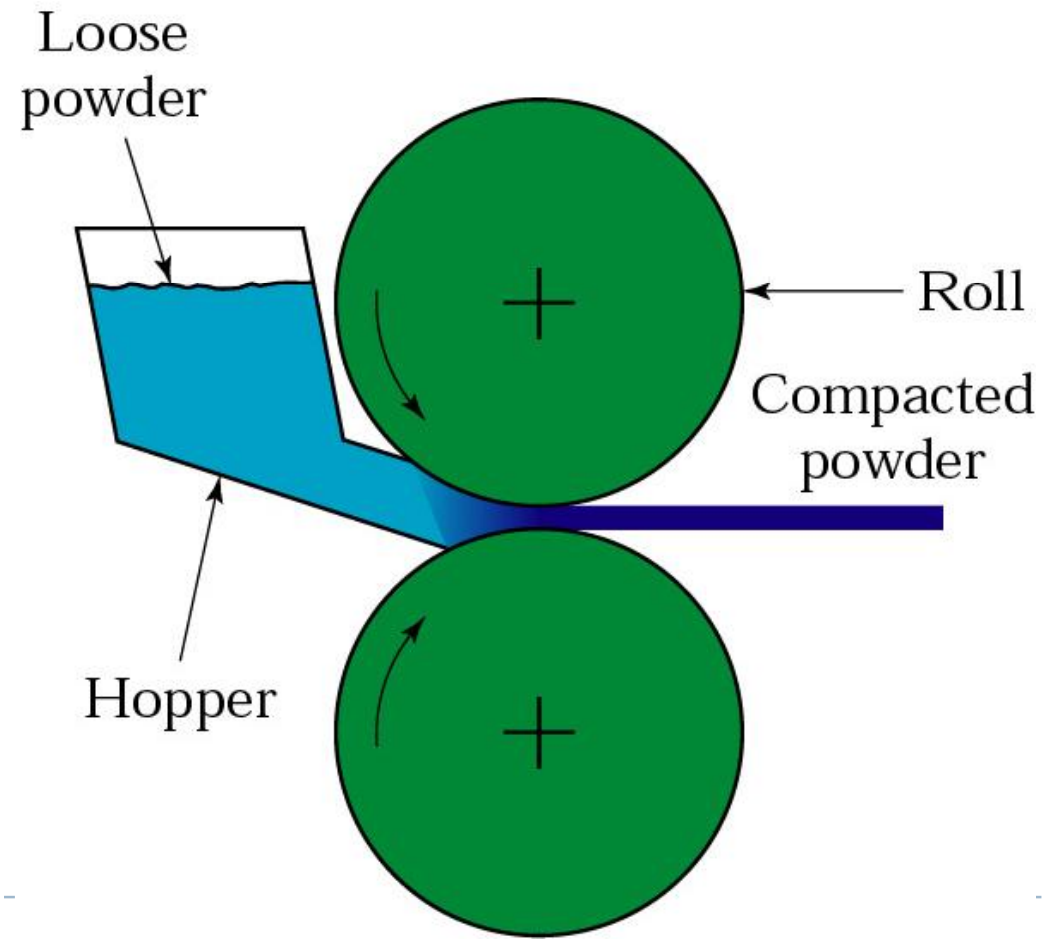
8-OTHER COMPACTING AND SHAPING OPERATIONS

- Rolling
- Extrusion
- Spray Deposition

Powder Rolling



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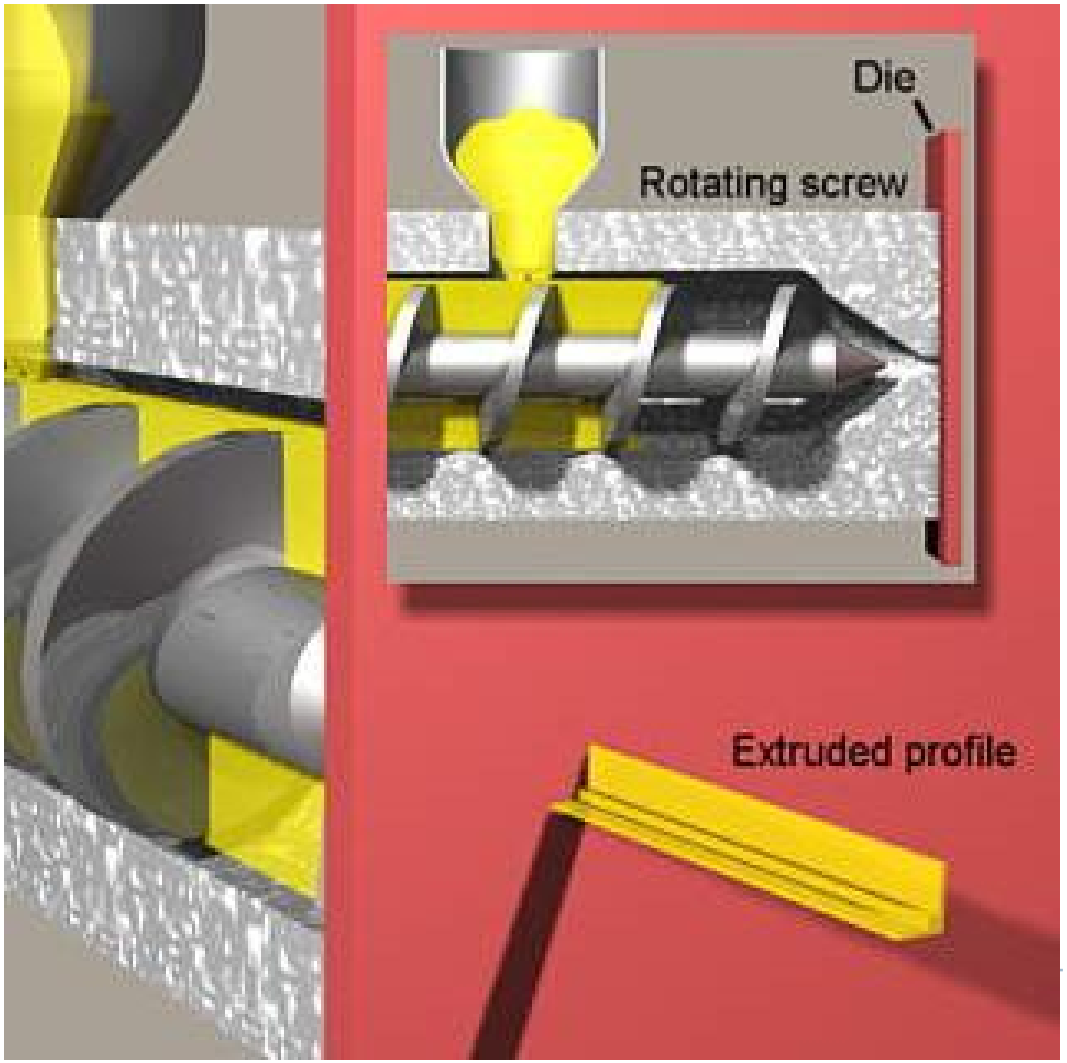
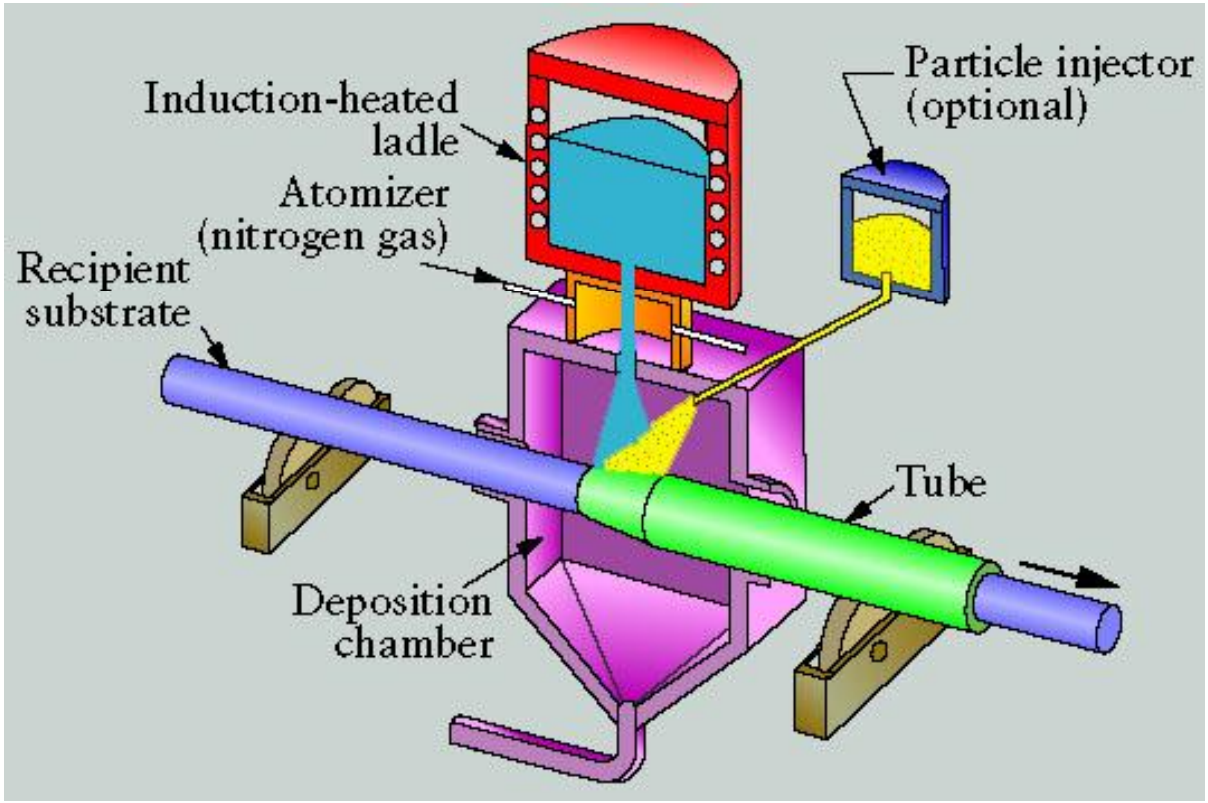
Powder Extrusion

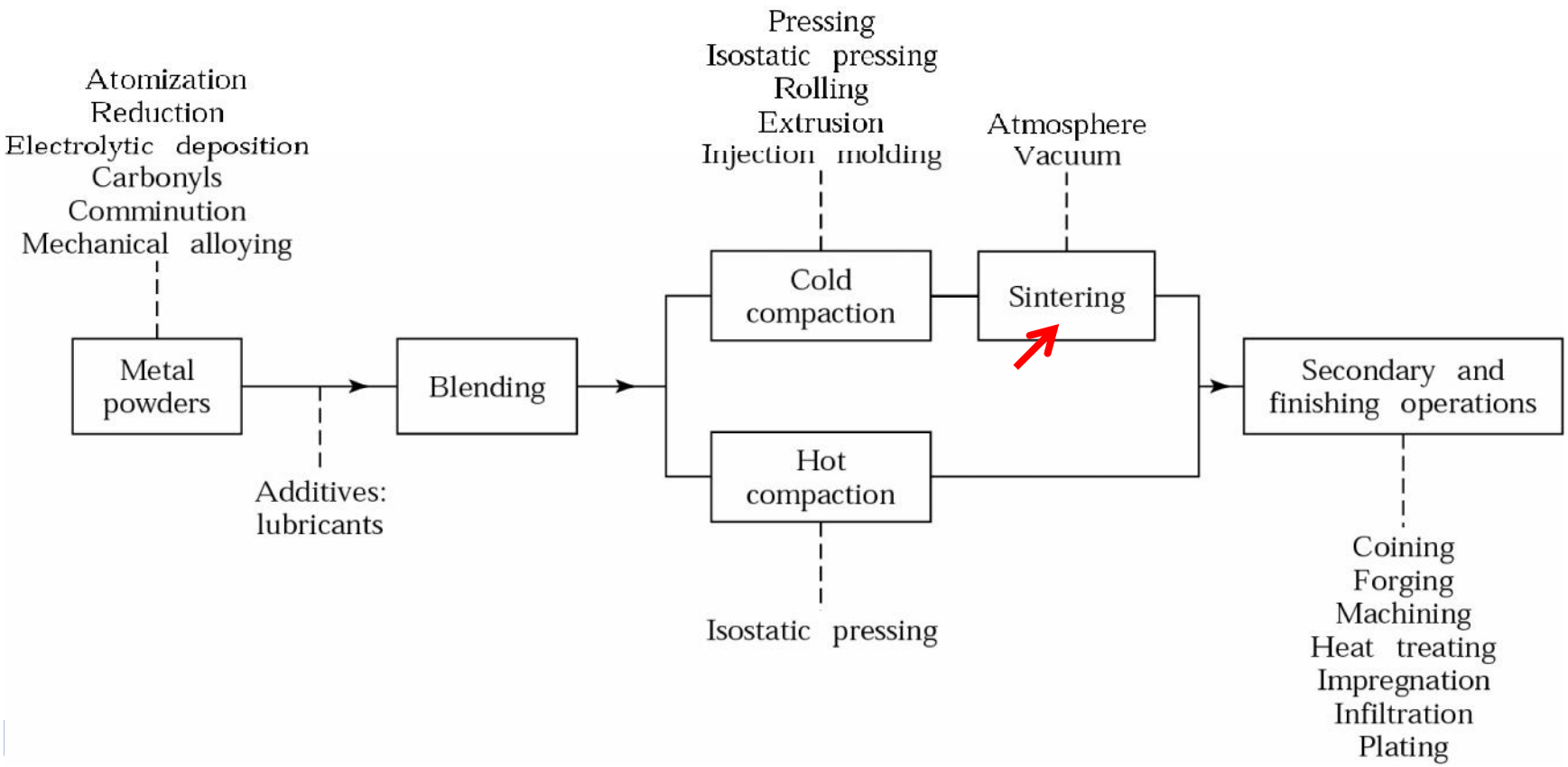


Spray Casting



Spray casting (Osprey process) in which molten metal is sprayed over a rotating mandrel to produce seamless tubing and pipe..

Making Powder-Metallurgy Parts



9- SINTERING

- 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

Sintering on Particles

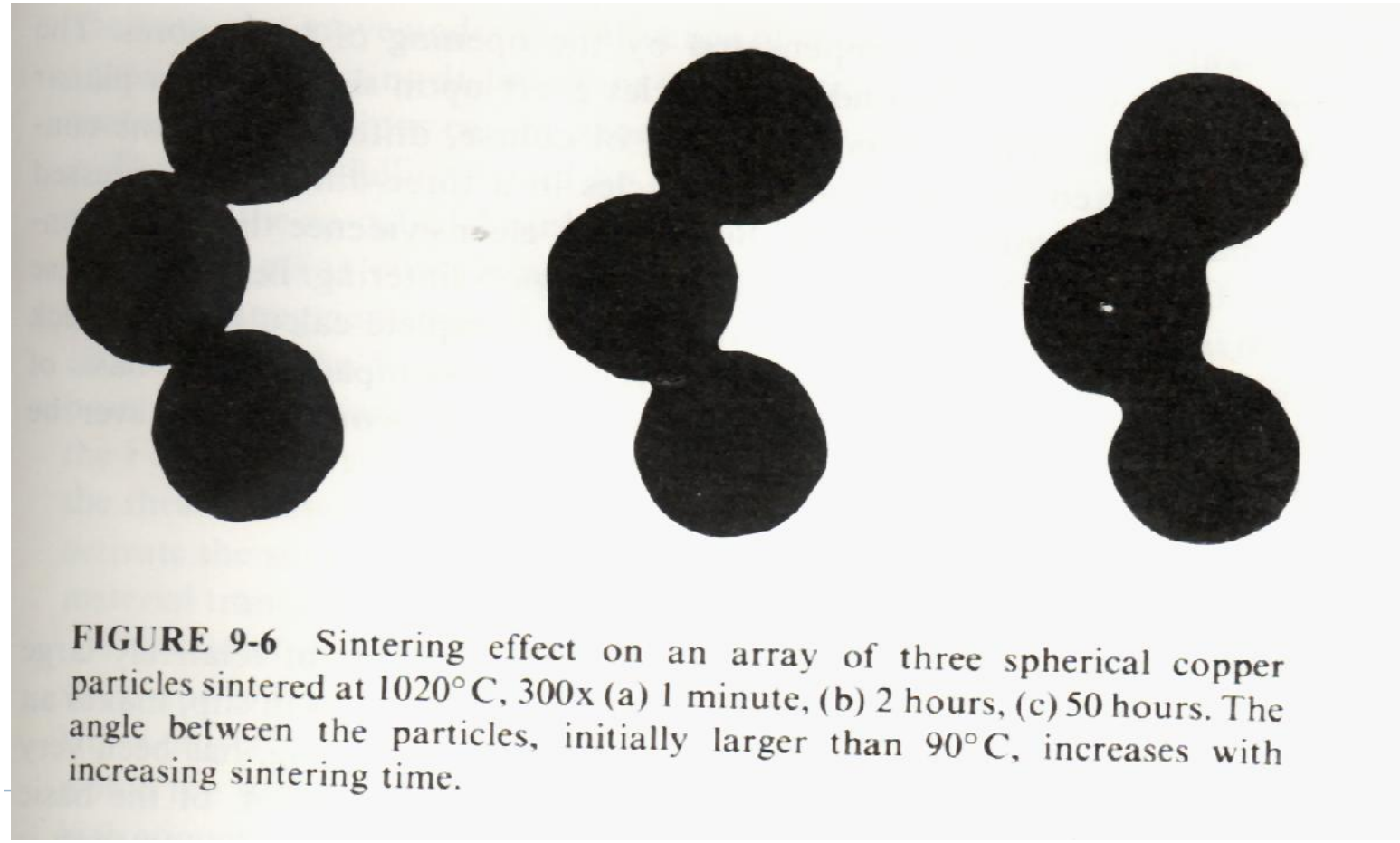


FIGURE 9-6 Sintering effect on an array of three spherical copper particles sintered at 1020°C, 300x (a) 1 minute, (b) 2 hours, (c) 50 hours. The angle between the particles, initially larger than 90°C, increases with increasing sintering time.

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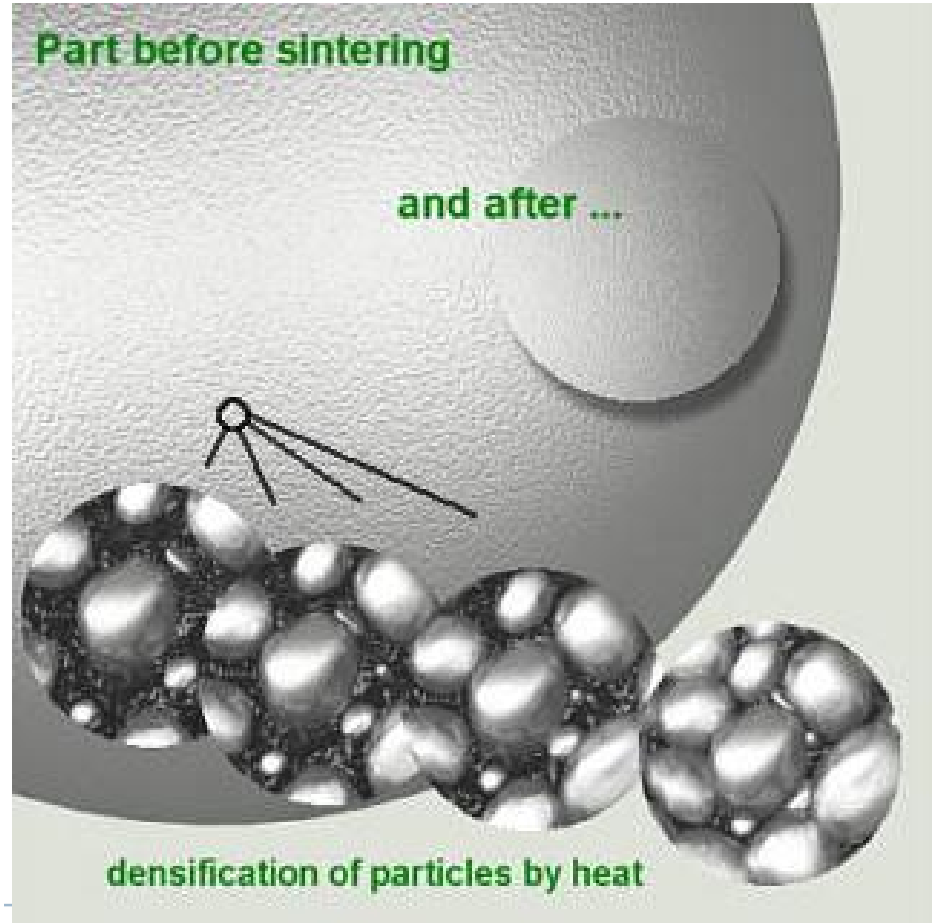
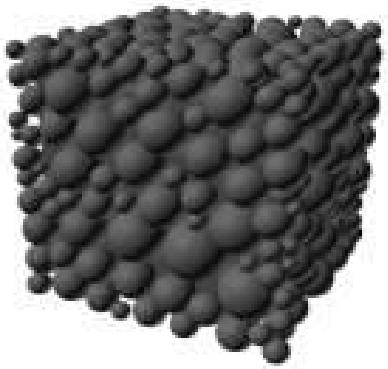
Sintering



Powder Compaction and Sintering

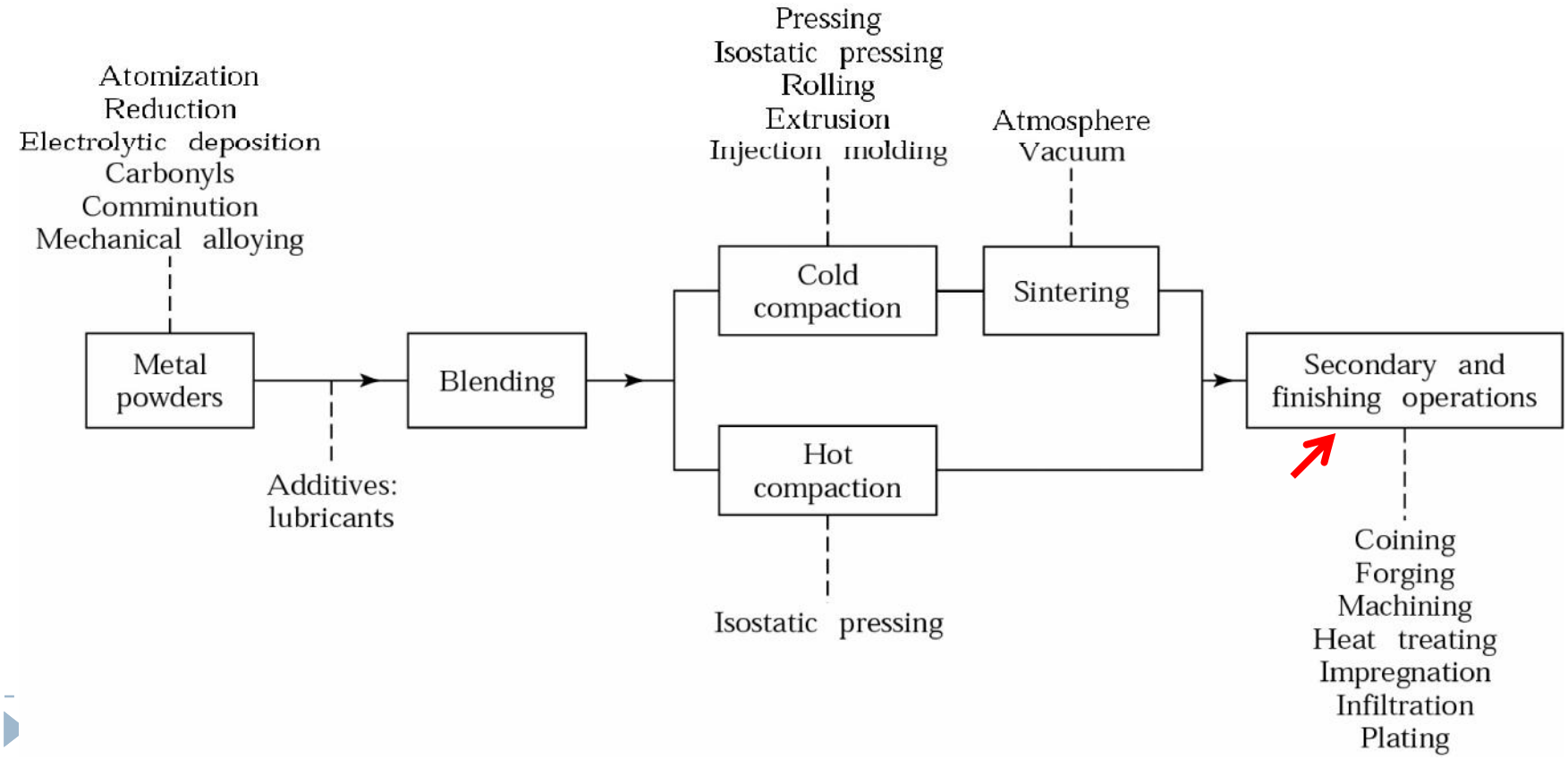
Raw powder



Formed product

Sintered product

Making Powder-Metallurgy Parts



10- SECONDARY OPERATIONS

- Most powder metallurgy products are ready to use after the sintering process
- Some products may use secondary operation to provide enhanced precision, improved properties, or special characteristics
- Distortion may occur during nonuniform cool-down so the product may be repressed, coined, or sized to improve dimensional precision

Secondary Operations (CONT.)

- If massive metal deformation takes place in the second pressing, the operation is known as P/M forging
  - Increases density and adds precision
- Infiltration and impregnation- oil or other liquid is forced into the porous network to offer lubrication over an extended product lifetime
- Metal infiltration fills in pores with other alloying elements that can improve properties
- P/M products can also be subjected to the conventional finishing operations: heat treatment, machining, and surface treatments

11- PROPERTIES OF P/M PRODUCTS

- The properties of P/M products depend on multiple variables
  - Type and size of powder
  - Amount and type of lubricant
  - Pressing pressure
  - Sintering temperature and time
  - Finishing treatments
- Mechanical properties are dependent on density
- Products should be designed (and materials selected) so that the final properties will be achieved with the anticipated final porosity

12- DESIGN OF POWDER METALLURGY PARTS

- Basic rules for the design of P/M parts
  - Shape of the part must permit ejection from die
  - Powder should not be required to flow into small cavities
  - The shape of the part should permit the construction of strong tooling
  - The thickness of the part should be within the range for which P/M parts can be adequately compacted
  - The part should be designed with as few changes in section thickness as possible

Powder Metallurgy Products

- Porous or permeable products such as bearings, filters, and pressure or flow regulators
- Products of complex shapes that would require considerable machining when made by other processes
- Products made from materials that are difficult to machine or materials with high melting points
- Products where the combined properties of two or more metals are desired
- Products where the P/M process produces clearly superior properties
- Products where the P/M process offers and economic advantage

Summary

- Powder metallurgy can produce products out of materials that are otherwise very difficult to manufacture
- P/M products can be designed to provide the targeted properties
- Variations in product size, production rate, quantity, mechanical properties, and cost

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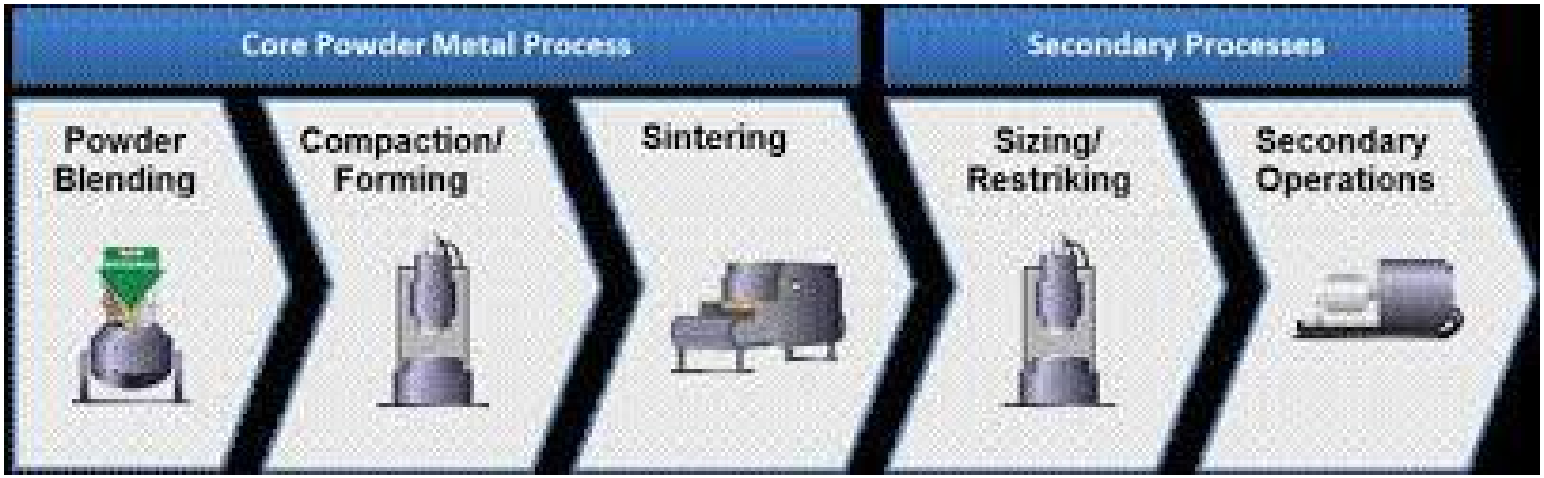

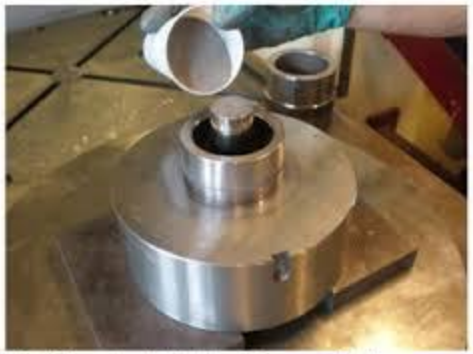

Fig. 2. Experimental tooling during powder fill (Courtesy Strecon)