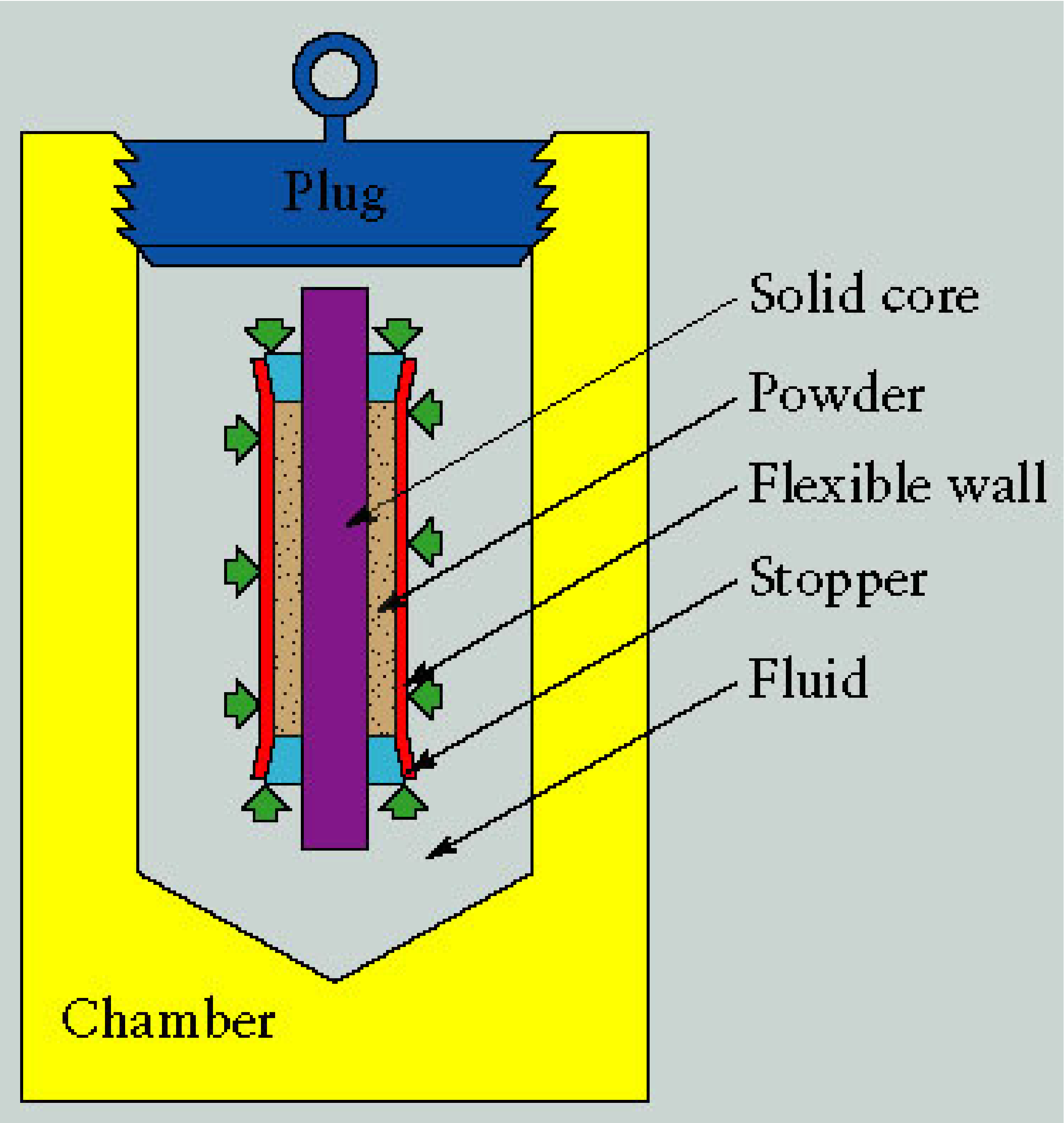
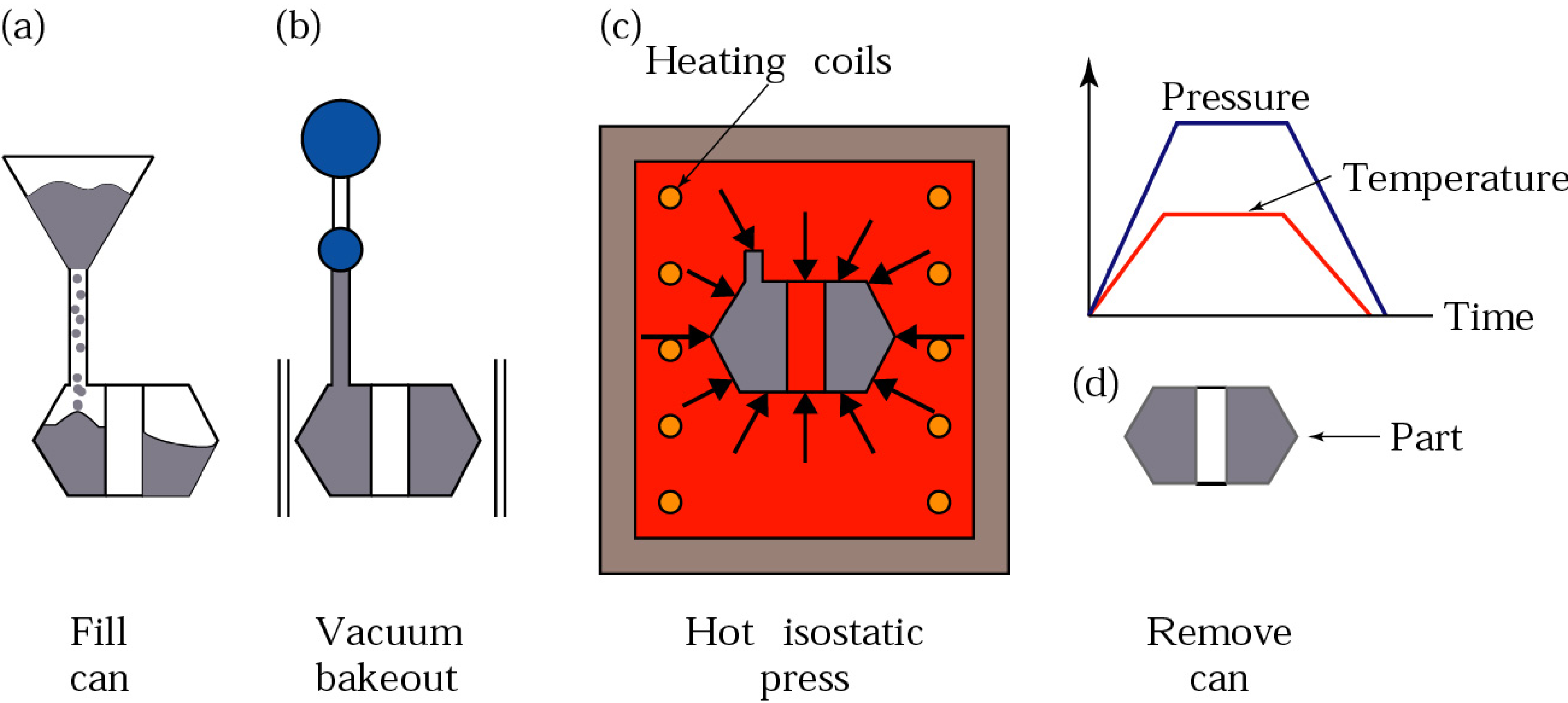
COMPACTION - Pressure



Cold Isostatic pressing

COMPACTION - Pressure



Hot Isostatic pressing

Isostatic Press

COMPACTION - Pressure

COLD ISOSTATIC PRESSING

- Placement of powder in flexible rubber mold
- Hydrostatic pressurization in chamber by water
- Most common pressure of 400 MPa
- Automotive cylinder liner (typical application)

HOT ISOSTATIC PRESSING

- powder container is usually made up of high melting point sheet metal
- inert gas (pressurizing media)
- 100 MPa, 1100°C (common conditions)
- Compacts of 100% density, good metallurgical bonding, good mechanical properties (advantages)
- wider dimensional tolerances, greater cost & time (limitations)

COMPACTION - Pressure

HIGH ENERGY RATE TECHNIQUES

- Explosive or spark discharge methods are applied in closed die
- Short time & high pressures
- High punch & die wear, limited tolerances, high cost

VIBRATORY COMPACTION

- Simultaneous application of pressure & vibration
- Use of much lower pressures
- Complicated equipment design

CONTINUOUS COMPACTION

- Applied to simple shapes (rod, sheet, tube, plate etc)
- Flowing loose powder between a set of vertically oriented rolls at much lower speeds

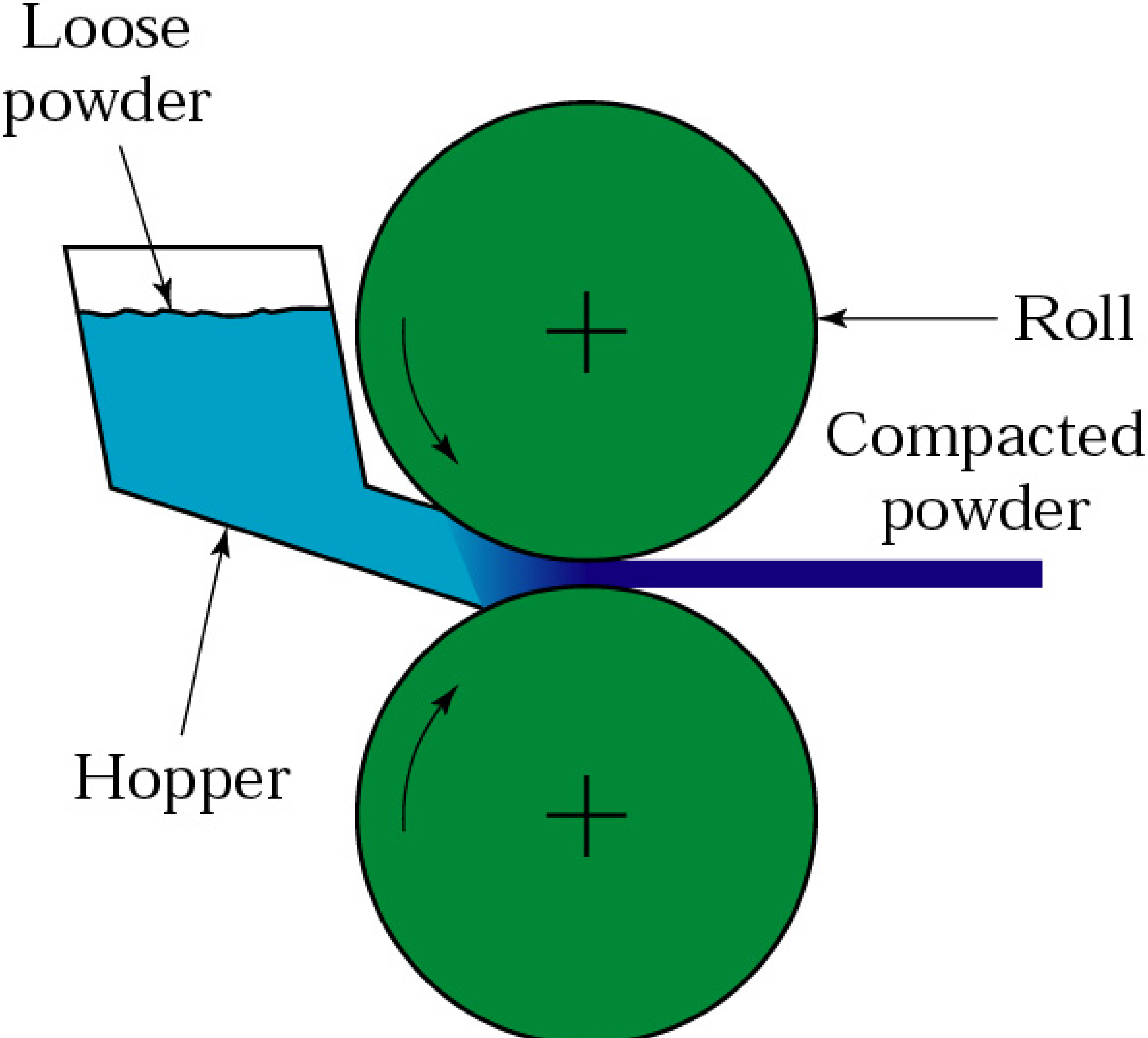
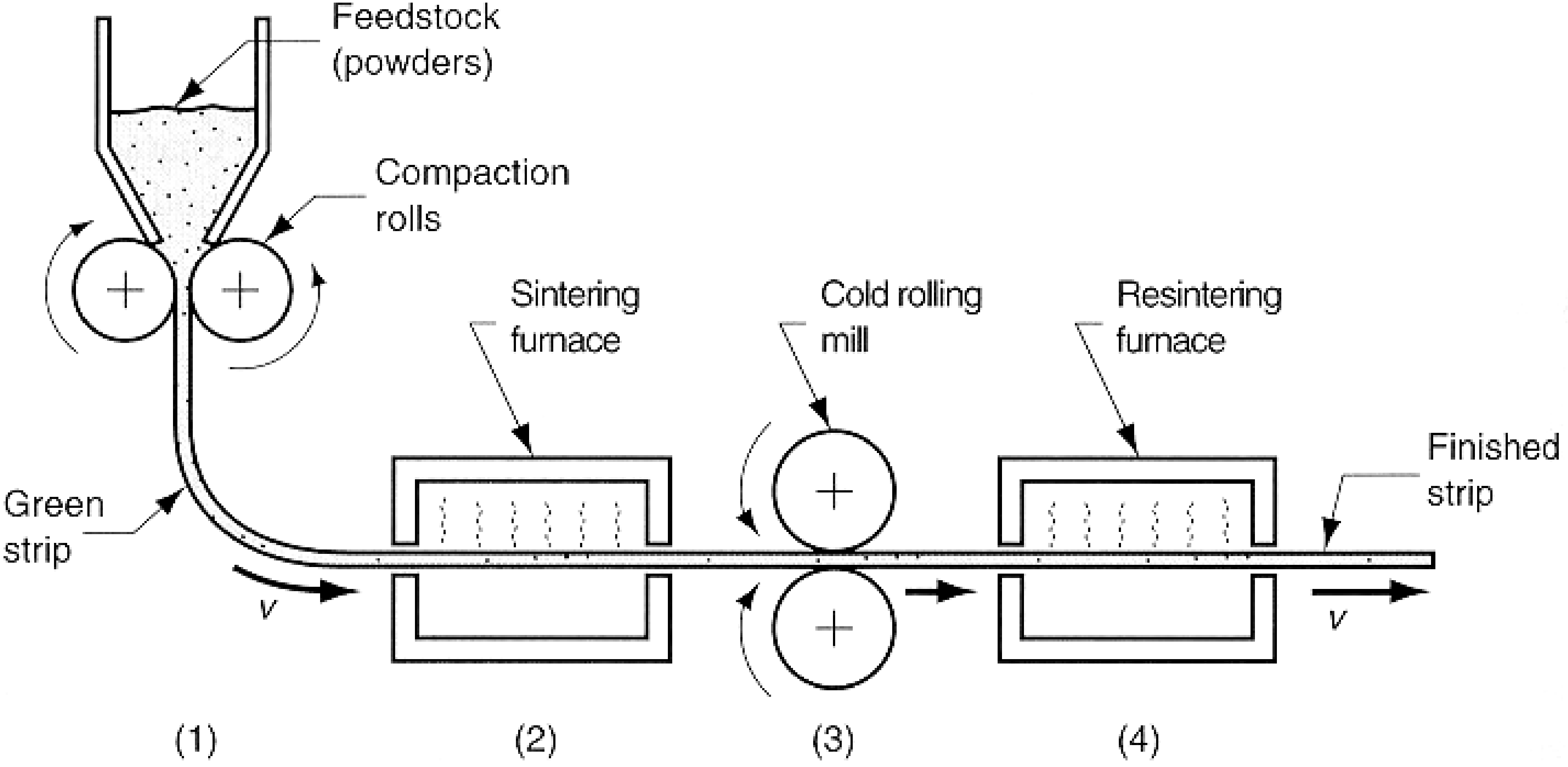
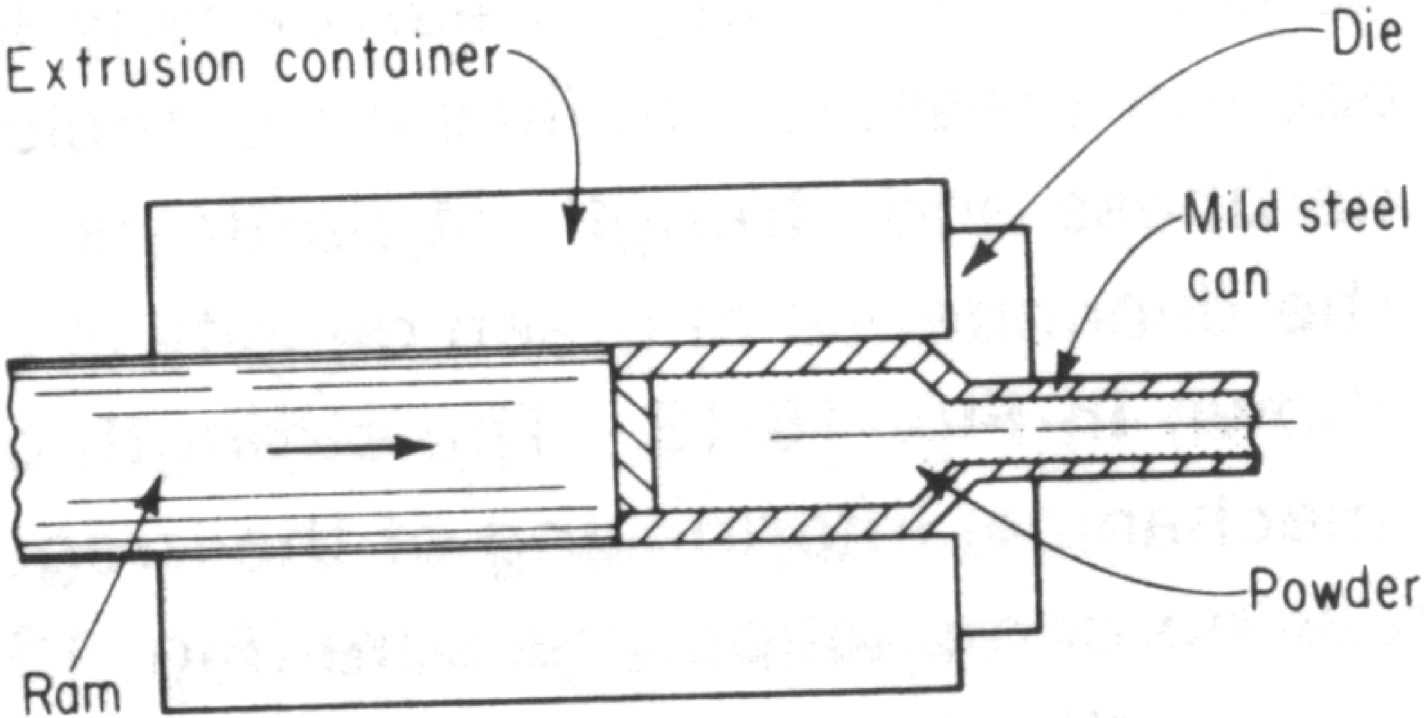

Loose
powder
Roll
Compacted
powder
Hopper

FIGURE 18.15 Powder rolling: (1) powders are fed through compaction rolls to form a green strip; (2) sintering; (3) cold rolling; and (4) resintering.

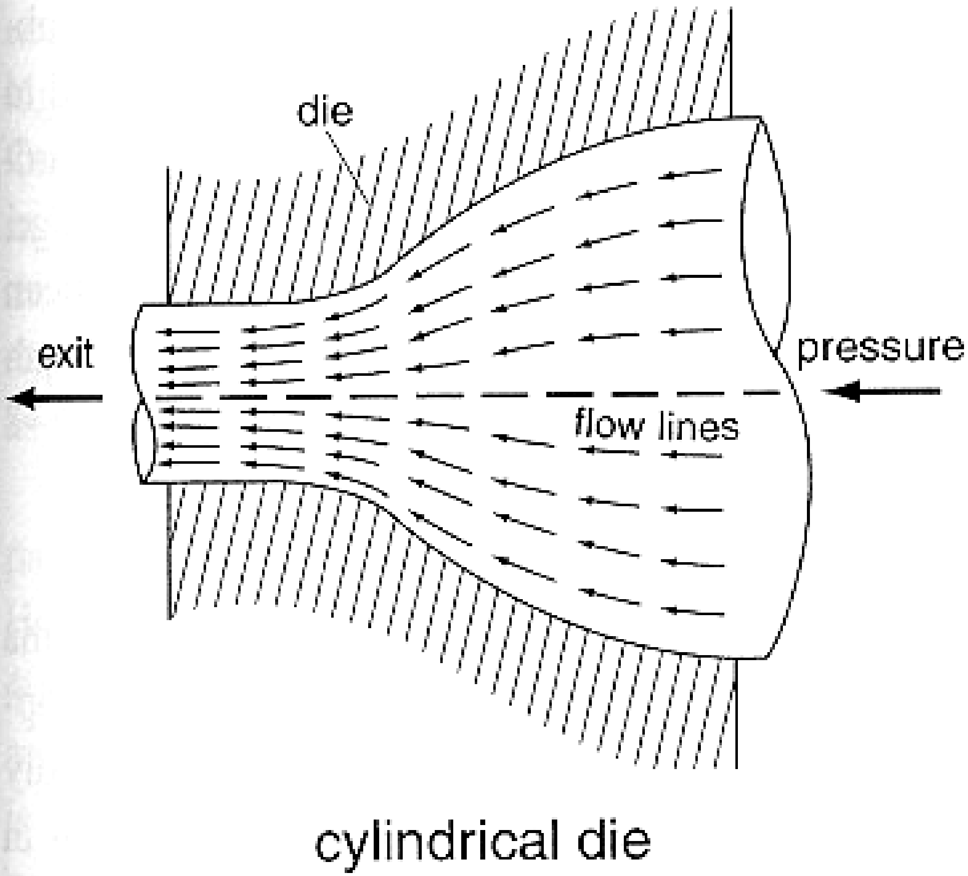


COMPACTION - Pressure



FORGING or EXTRUSION

- Canning of powder
- Heating or evacuation of sealed container followed by forging or evacuation
- Mechanical or chemical removal of container material



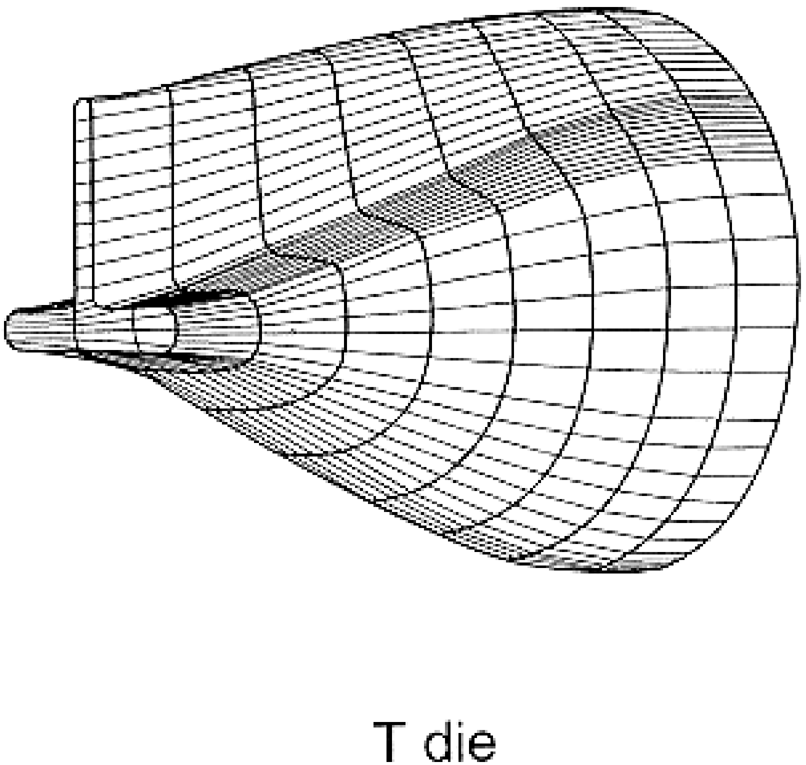
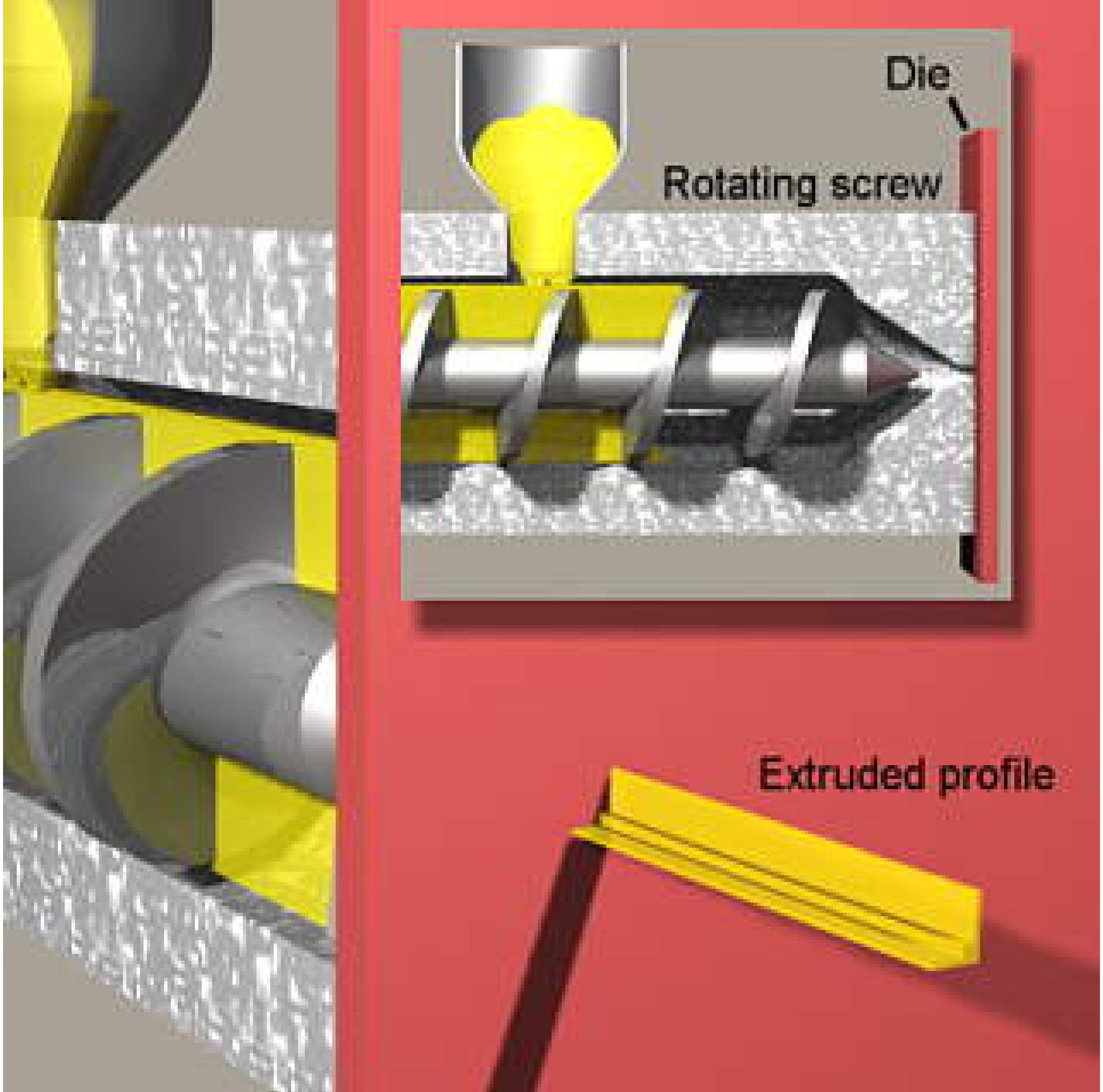


Figure 8.26. Streamlined die designs are used for smooth powder flow and densification. The contour changes in the die are calculated to ensure that the steel powder densifies into the final object shape without cracking. The left sketch shows an internal slice of a simple flow analysis, and the right sketch is an example die cavity for forming an extruded "T" section. (Based on work of H. Gegel, S. M. Malas, and S. M. Doraivelu.)


Die
Rotating screw
Extruded profile

COMPACTION - Pressureless

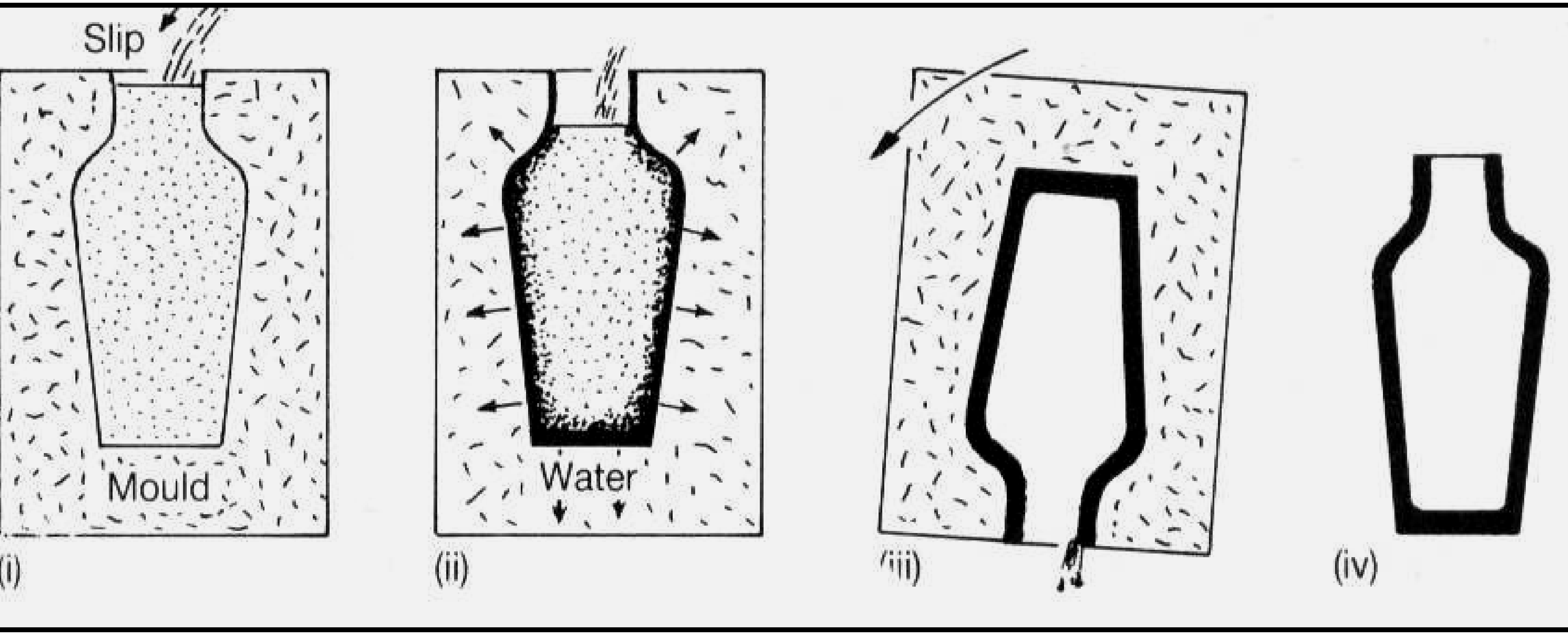
SLIP CASTING

- Preparation of slip (powder suspended in liquid and additives)
- Keeping slip in mold made up of fluid absorbing material
- Formation of slip casting
- Removal of slip followed by drying operation

GRAVITY COMPACTION

- Pouring loose powder under the influence of gravity
- Sintering in die
- Porous parts (no application of pressure)
- Widely used to manufacture metal filters

Slip-Casting



(i) Slip is first poured into an absorbent mould
(ii) a layer of clay forms as the mould surface absorbs water
(iii)when the shell is of suitable thickness excess slip is poured away
(iv)the resultant casting

COMPACTION - Pressureless

CONTINUOUS PRESSURELESS TECHNIQUE

- Application of power in the form of slurry

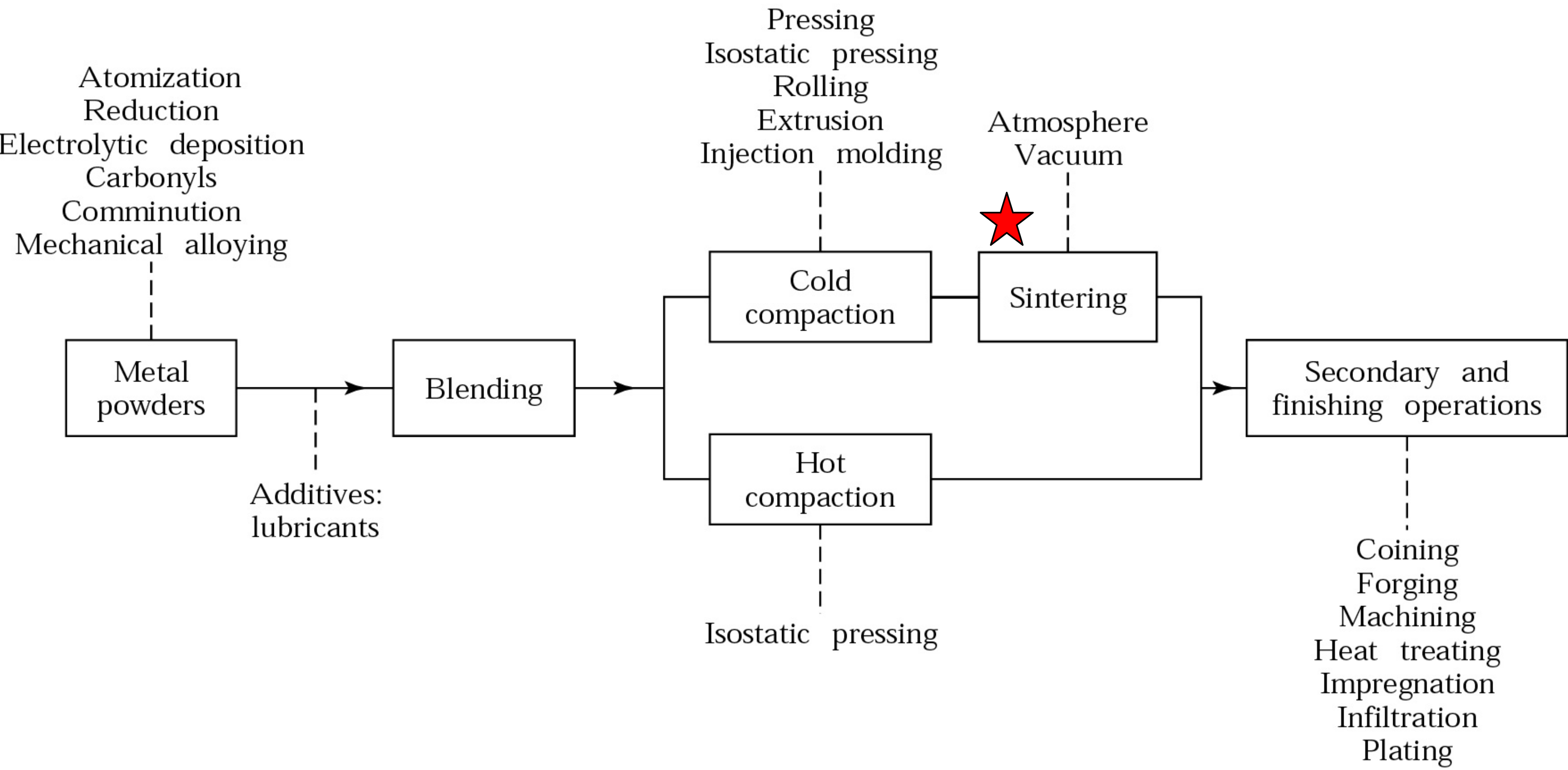
- Consolidation and drying

- Used to produce porous sheets for electrodes of nickel-cadmium batteries

TABLE 18-1 Typical Compacting Pressures for Various Applications

Application	Compaction Pressures tons/in.^{2}	Compaction Pressures 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

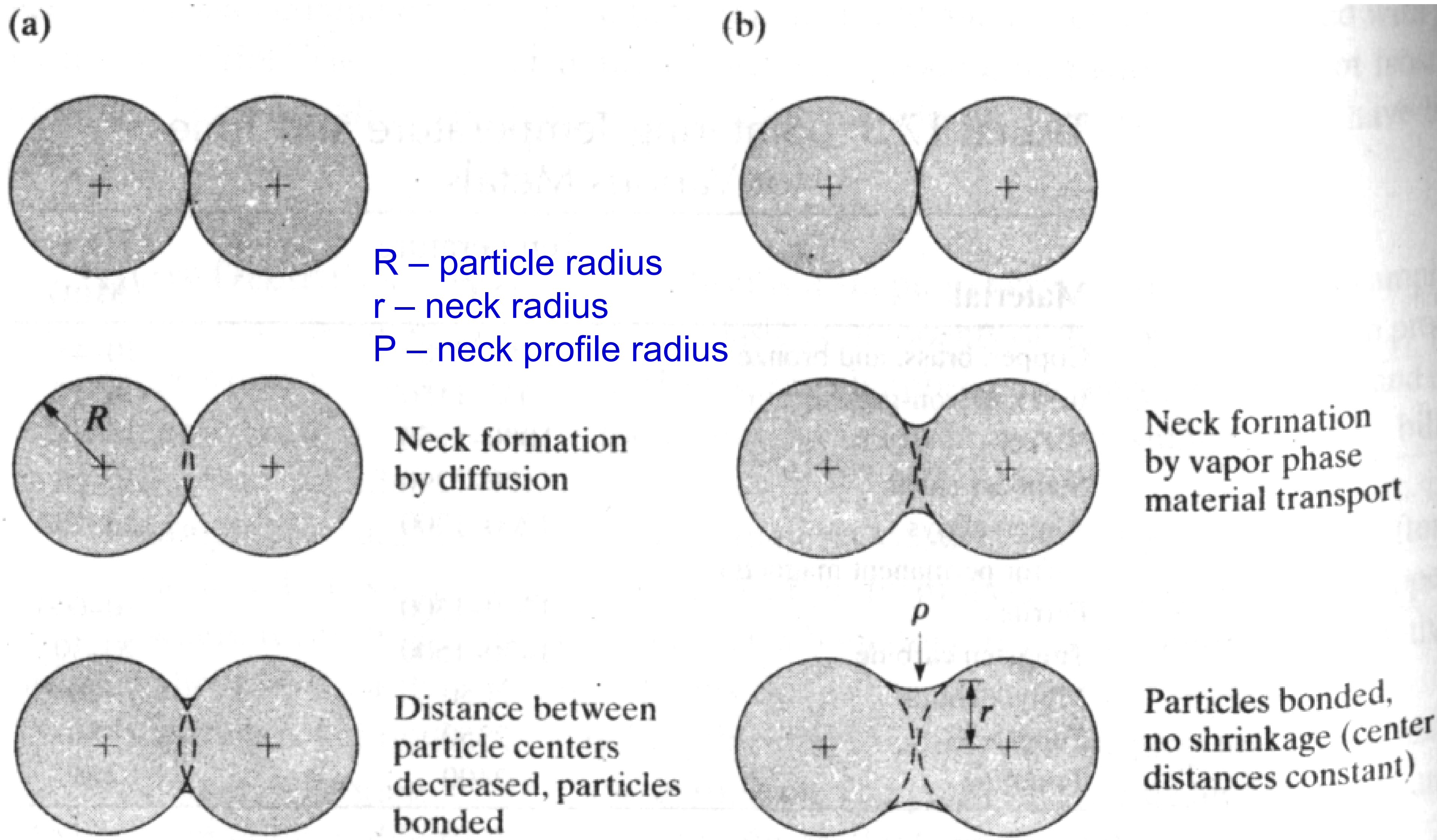
(Left) Typical press for the compacting of metal powders. A removable die set (right) allows the machine to be producing parts with one die set while another is being fitted to produce a second product.


Atomization
Reduction
Electrolytic deposition
Carbonyls
Comminution
Mechanical alloying
Metal powders
Additives: lubricants
Blending
Pressing
Isostatic pressing
Rolling
Extrusion
Injection molding
Cold compaction
Hot compaction
Isostatic pressing
Atmosphere
Vacuum
Sintering
Secondary and finishing operations
Coining
Forging
Machining
Heat treating
Impregnation
Infiltration
Plating

SINTERING

- Purpose - to increase strength & hardness of a green compact
- Carried out at a temperature below the highest melting constituent
- Furnaces may be either the electric resistance, gas fired or oil fired type.
- Principal variables – temperature (generally within 70 – 90% of the melting point of metal or alloy), time (10 min. – 8 hours) & furnace atmosphere
- Sintering process is concerned with
  - diffusion (surface of particles as temperature rises)
  - densification (decreases porosity, increases particle contact area)
  - recrystallization & grain growth (between particles at the contact area)

SINTERING



R – particle radius
r – neck radius
P – neck profile radius

Solid state material transport

Liquid state material transport

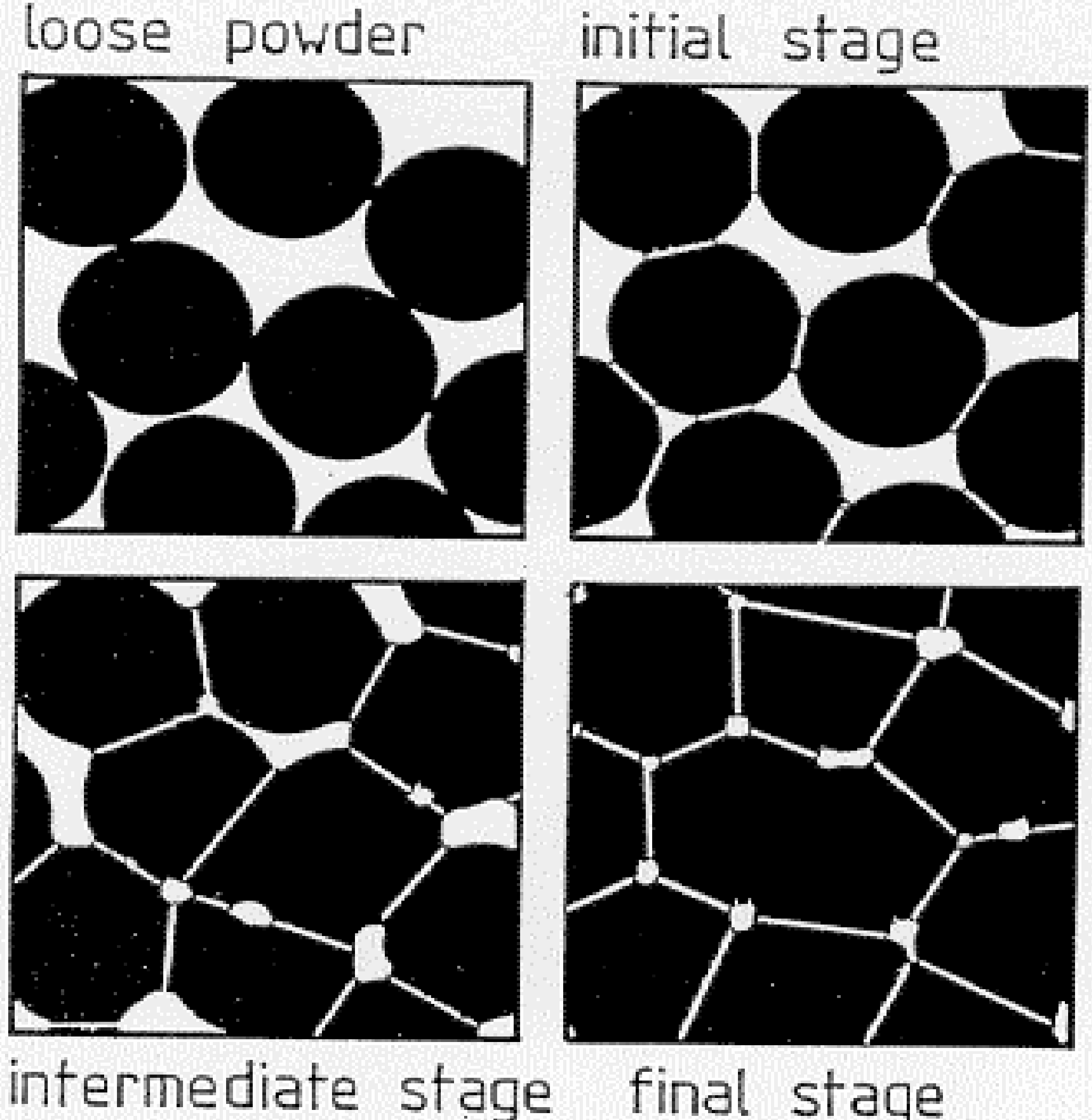
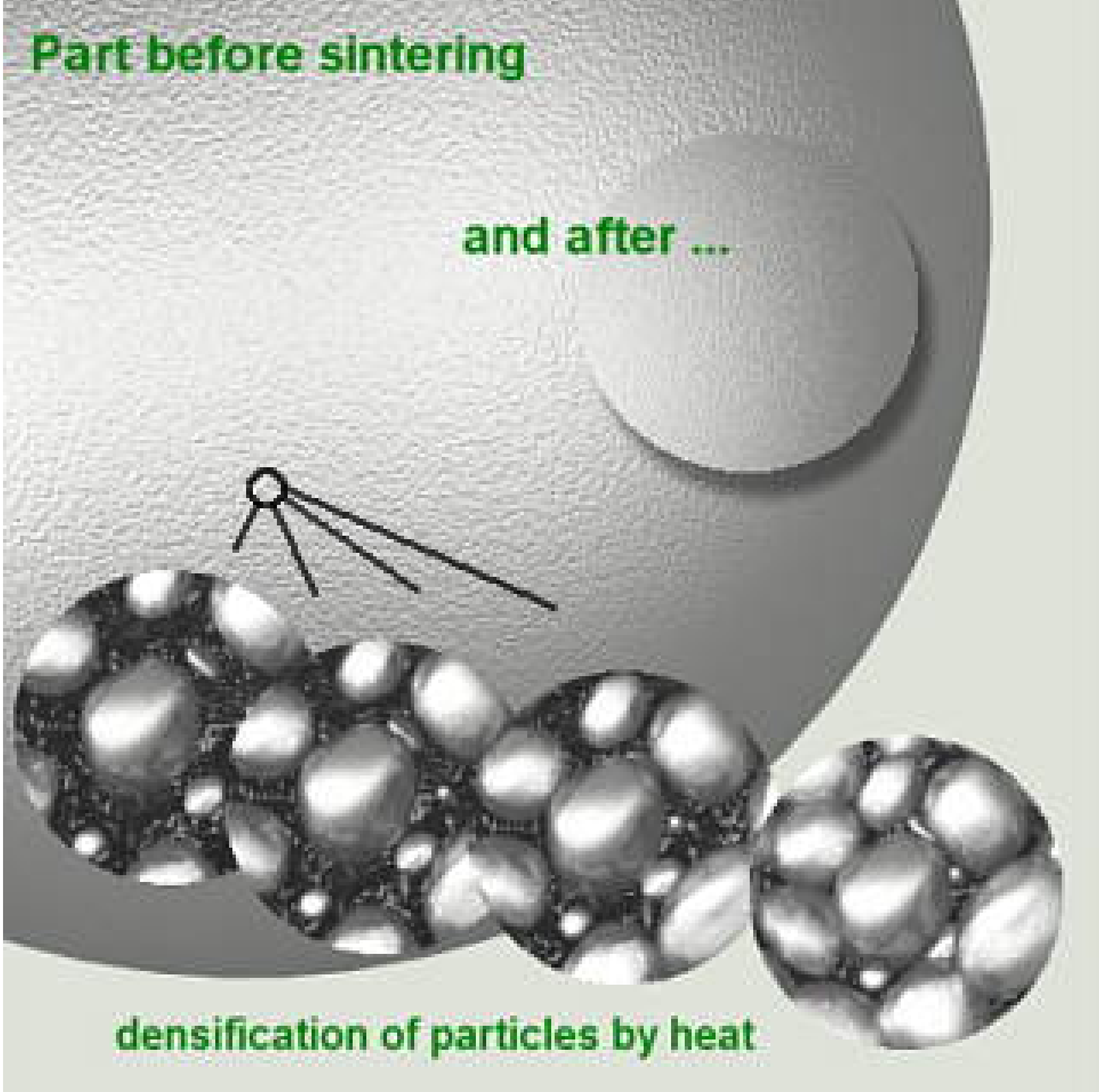
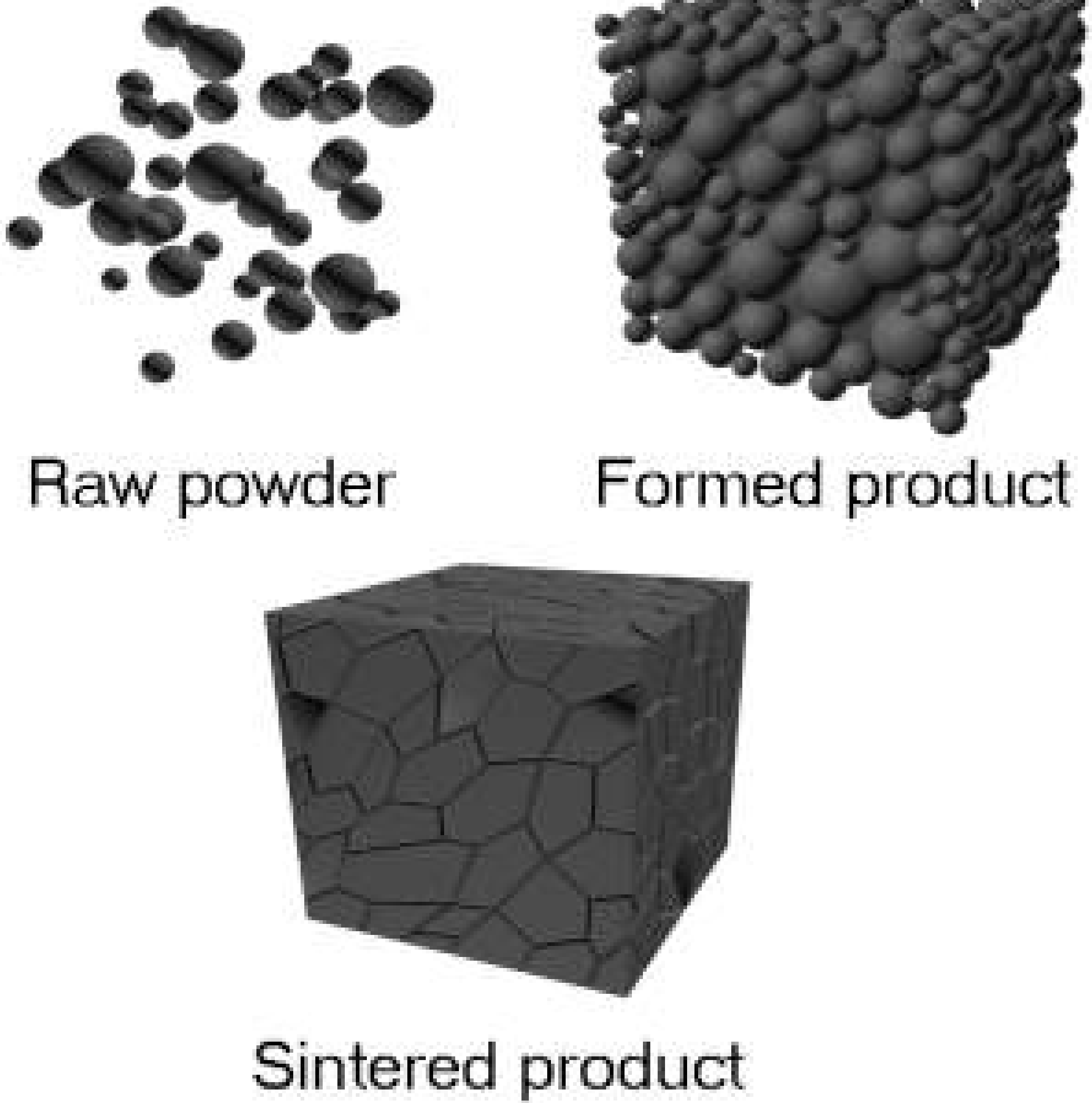


Figure 1: Schematic of loose powder sintering (20).


Part before sintering
and after ...
densification of particles by heat


Raw powder
Formed product
Sintered product

SINTERING

Decrease in free energy due to decrease of surface area

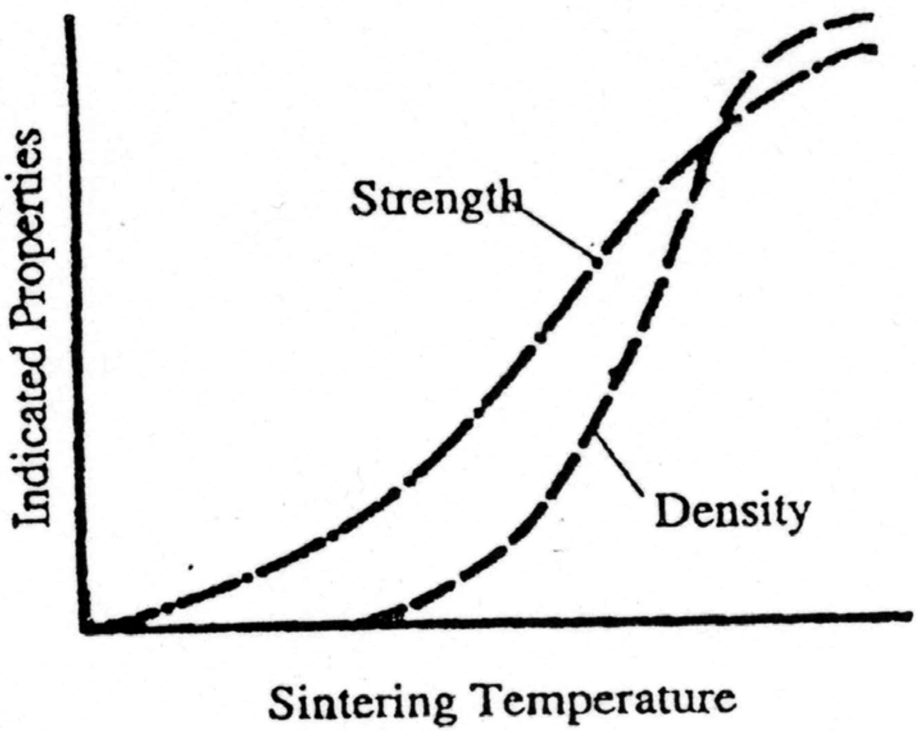
SOLID STATE TRANSPORT

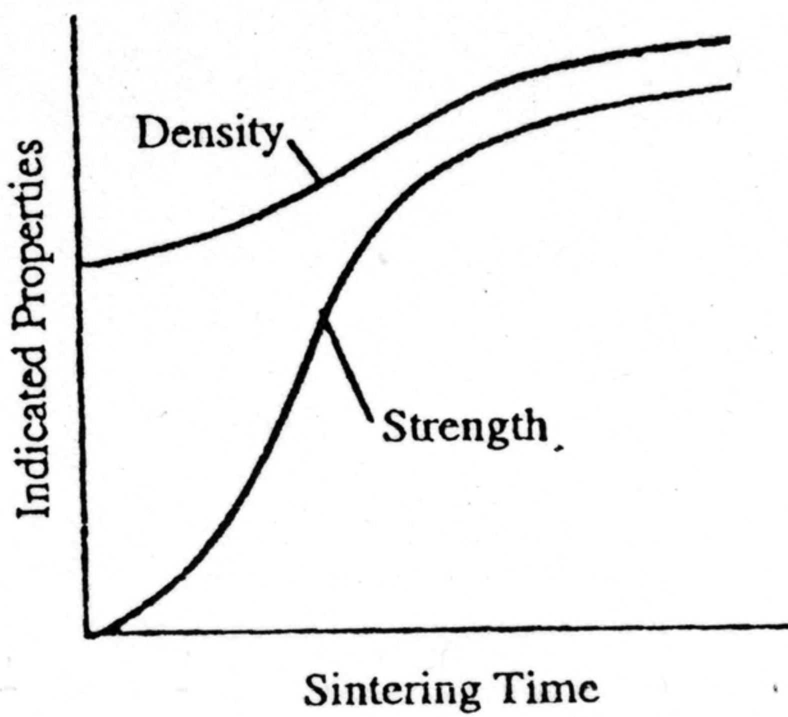
- With rise in temperature bonding of two adjacent particles begins
- Heating of green compact above recrystallization temperature of low melting metal

LIQUID STATE TRANSPORT

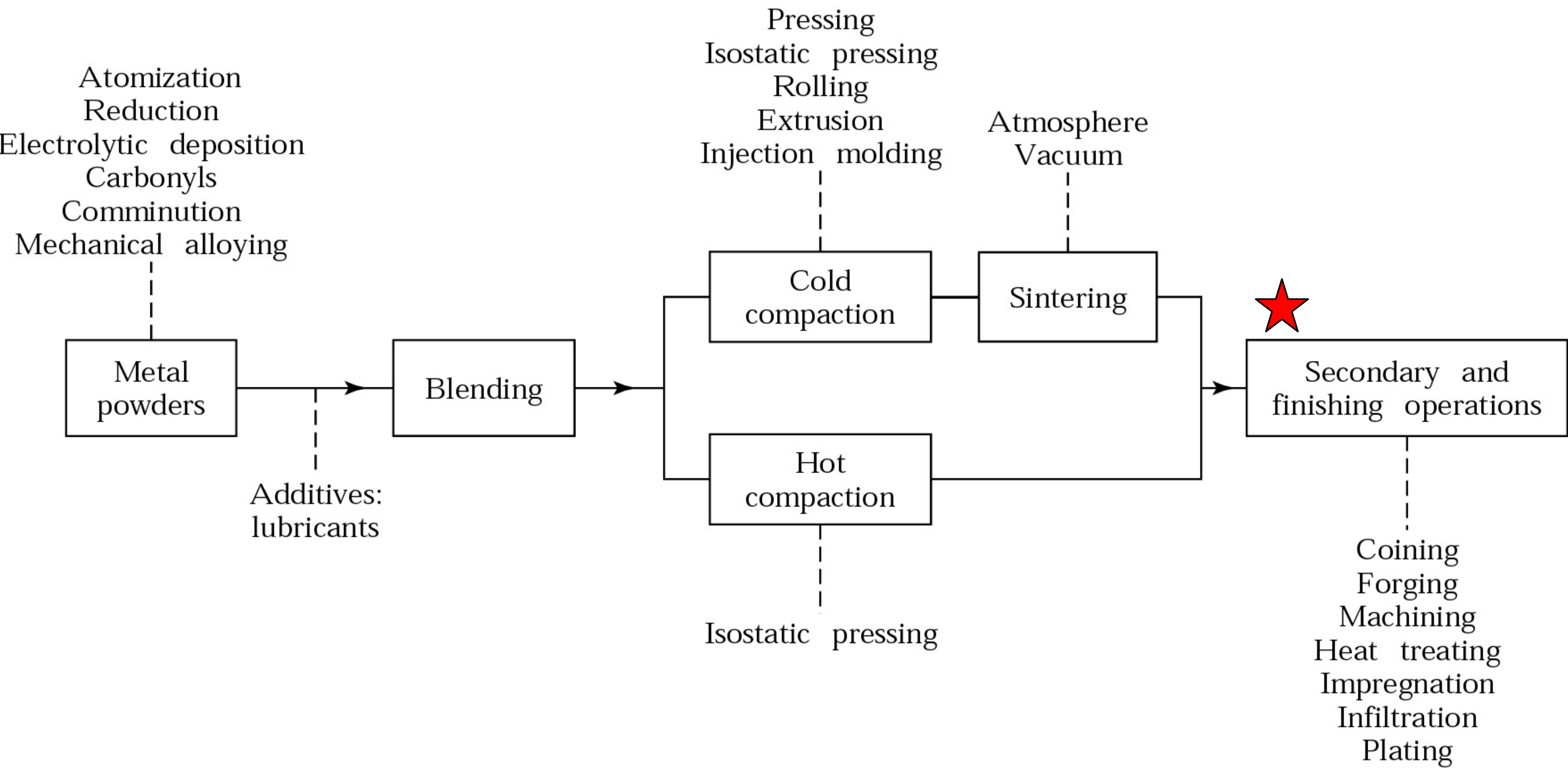
- Carried out above the melting point of one of the alloy constituents or above the melting point of an alloy formed during sintering

Metal powder	Sintering temperature °C	Sintering time (min)
Brass	850-900	10-45
Bronze	750-880	10-20
Copper	850-900	10-45
Iron	1000-1150	10-45
Nickel	1000-1150	30-45
Stainless steel	1100-1300	30-60
Tungsten	2350	480
Tungsten carbide	1420-1500	20-30


Indicated Properties
Strength
Density
Sintering Temperature


Indicated Properties
Density
Strength
Sintering Time

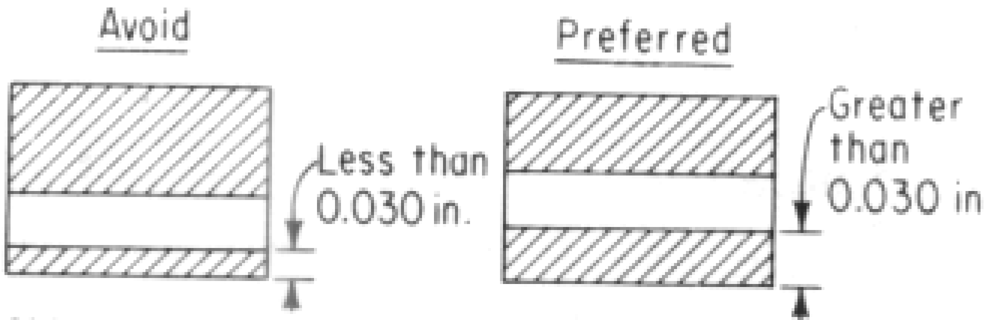
Sintering Production Lines


Atomization
Reduction
Electrolytic deposition
Carbonyls
Comminution
Mechanical alloying
Metal powders
Additives: lubricants
Blending
Pressing
Isostatic pressing
Rolling
Extrusion
Injection molding
Cold compaction
Hot compaction
Isostatic pressing
Atmosphere
Vacuum
Sintering
Secondary and finishing operations
Coining
Forging
Machining
Heat treating
Impregnation
Infiltration
Plating

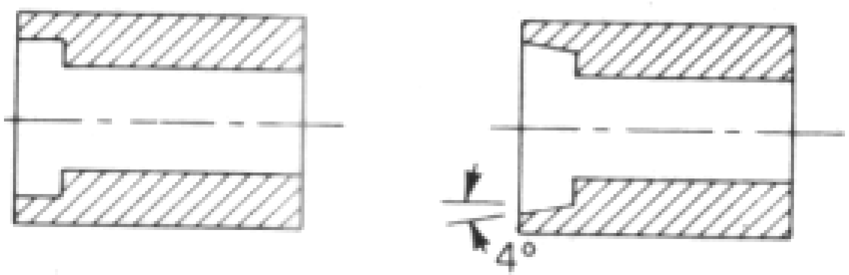
SUPPLIMENTAL OPERATIONS

1. Coining or pressing
   - cold working process
   - condensation of sintered product
2. Impregnation
   - impregnation with heated oil (self lubricated bearings)
3. Infiltration
   - placement of slug of a lower melting point metal against the sintered part
   - heating of assembly to melt the slug
   - infiltration of molten metal by capillary action
4. Heat treatment

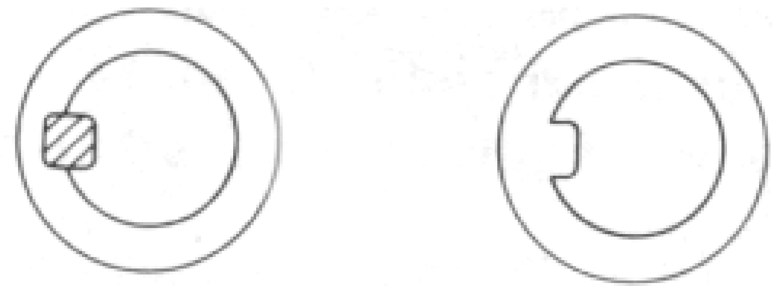
DESIGN CONSIDERATIONS



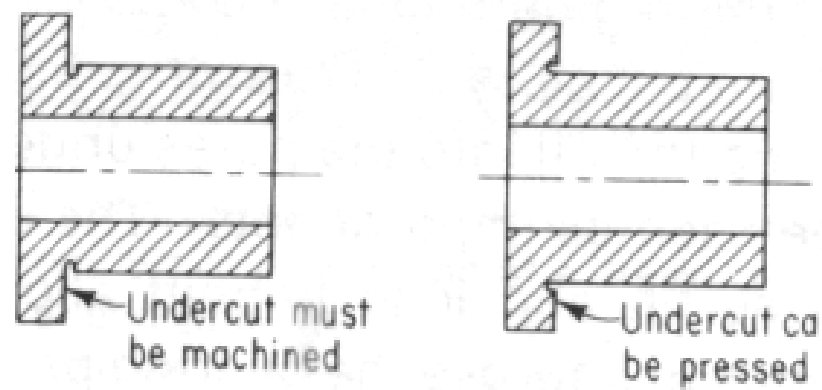
Sidewalls should be thicker than 0.030 in.



A tapered counterbore strengthens the tool and aids in tool removal

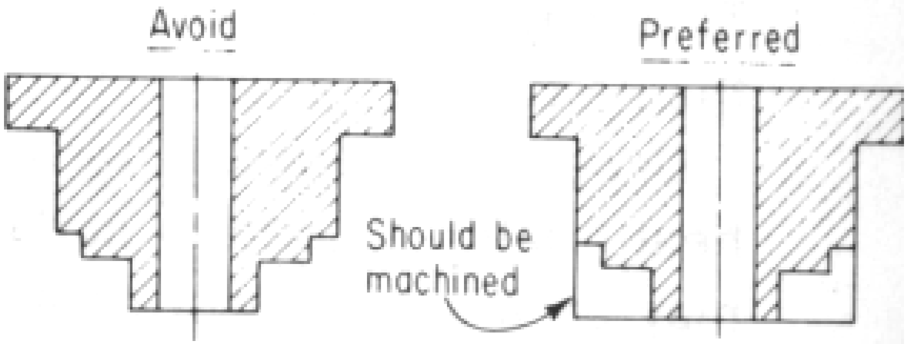


Eliminate separate key and keyway; a keyed bushing can be pressed

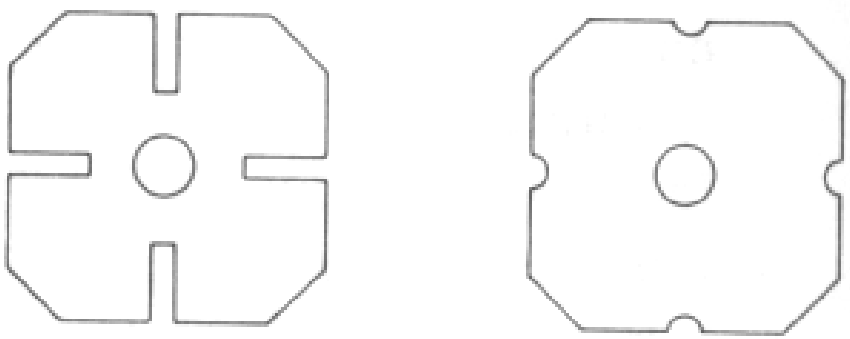


Flange relief can be pressed to save machining

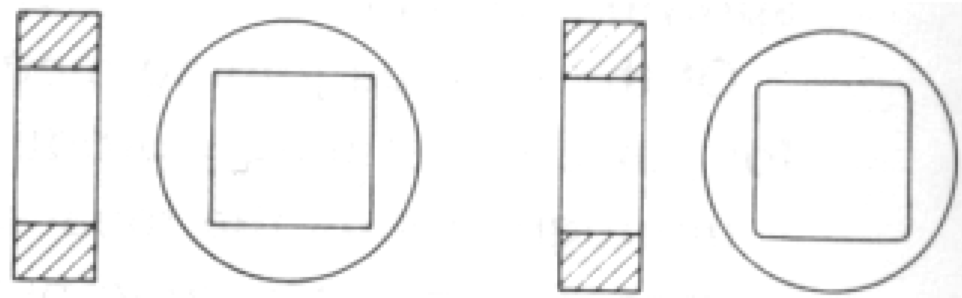
DESIGN CONSIDERATIONS



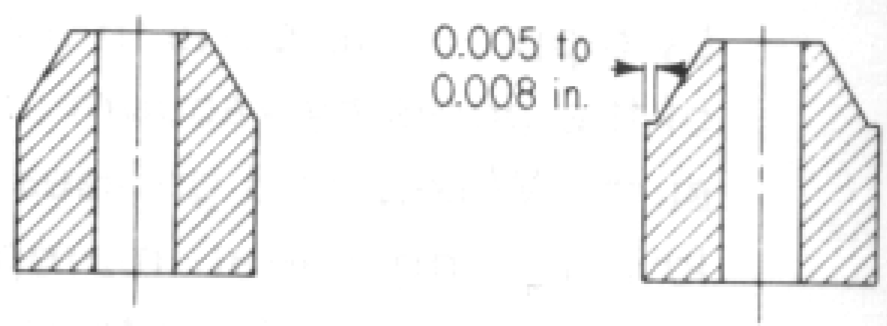
Part has lower strength if all steps are pressed



Avoid deep, narrow splines



Rounded corners permit uniform powder flow in the die



End a taper with a small land area

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

BASIC RULES FOR THE DESIGN OF P/M PARTS

- Parts can be designed to take advantage of the fact that certain forms and properties can be produced by P/M that are impossible, impractical, or uneconomical by any other method
- The design should be consistent with available equipment
- Consideration should be made for product tolerances
- Design should consider and compensate for dimensional changes that will occur after pressing

DEFECTS IN PM

- Improper density (green compact)
- Improper bonding (after compacting & sintering – presence of foreign materials)
- Inhomogeneous properties (improper lubrication)

ECONOMICS OF POWDER METALLURGY

- Competitive with casting and forging
- High initial cost
- Economical for quantities over 10,000 pieces
- Reduces or eliminates scraps

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

Disadvantages

- Inferior strength properties
- High tooling costs
- High material cost
- Size and shape limitations
- Dimensional changes during sintering
- Density variations
- Health and safety hazards

APPLICATIONS OF PM

1. Cemented carbide cutting tools
2. Heavy duty brake pads
3. Magnetic cores for transformers
4. Antifriction bearings
5. Bulb filaments

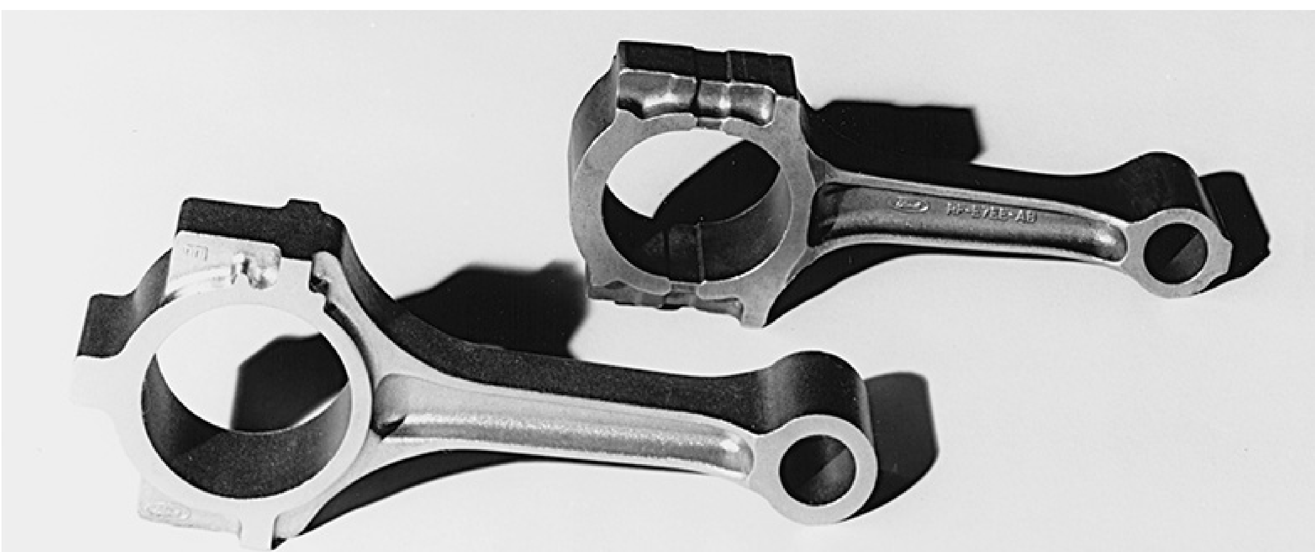
POWDER METALLURGY PRODUCTS

- 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

PROPERTIES OF P/M PRODUCTS

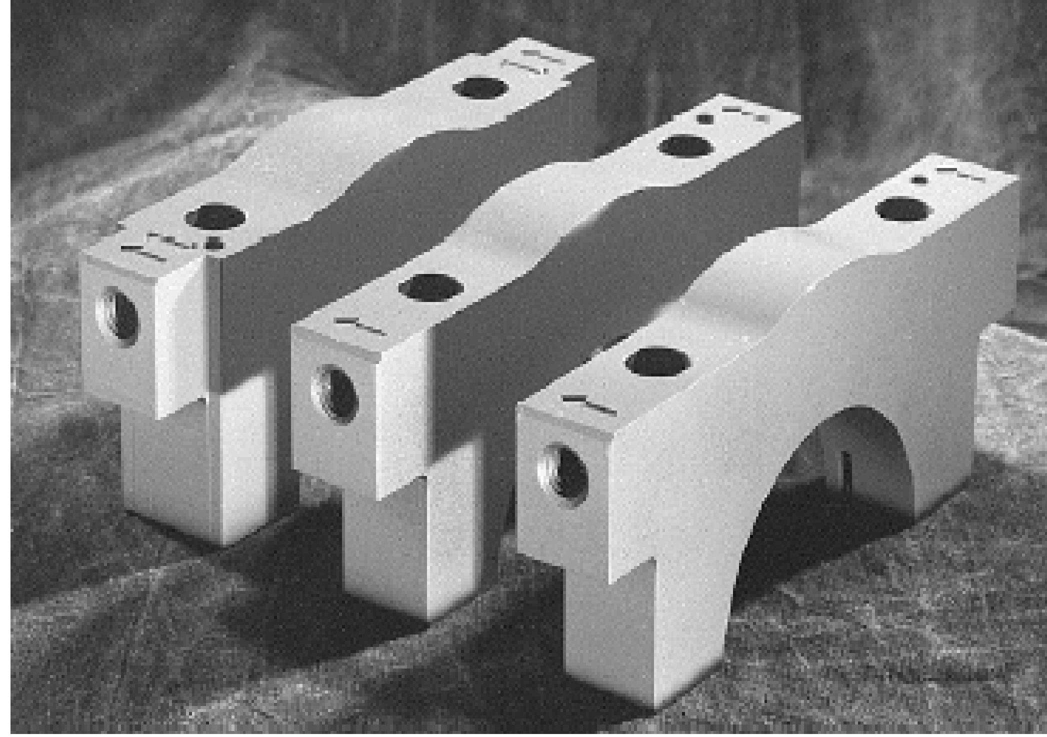
- The properties of P/M products depend on multiple variables
  - Type and size of powder
  - Amount and type of lubricant
  - Pressing pressure
  - Sintering temperature and time
  - Finishing treatments
- Mechanical properties are dependent on density
- Products should be designed (and materials selected)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

(Right) Comparison of conventional forging and the forging of a powder metallurgy preform to produce a gear blank (or gear). Moving left to right, the top sequence shows the sheared stock, upset section, forged blank, and exterior and interior scrap associated with conventional forging. The finished gear is generally machined from the blank with additional generation of scrap. The bottom pieces are the powder metallurgy preform and forged gear produced entirely without scrap by P/M forging.



P/M forged connecting rods have been produced by the millions. (Courtesy of Metal Powder Industries Federation, Princeton, NJ.)

a



c

b

(a)Examples of typical parts made by powder-metallurgy processes. (b) 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. (c) Main-bearing powder metal caps for 3.8 and 3.1 liter General Motors automotive engines.


QUALA-DIE


LIBERTY


LIBERTY


LIBERTY
IN GOD
WE TRUST
P
2002


LIBERTY
IN GOD WE TRUST
2002
BVLGARI

P/M MATERIALS

TABLE 18-5 Comparison of Properties of Powder Metallurgy Materials and Equivalent Wrought Metals (Note how porosity diminishes mechanical performance)

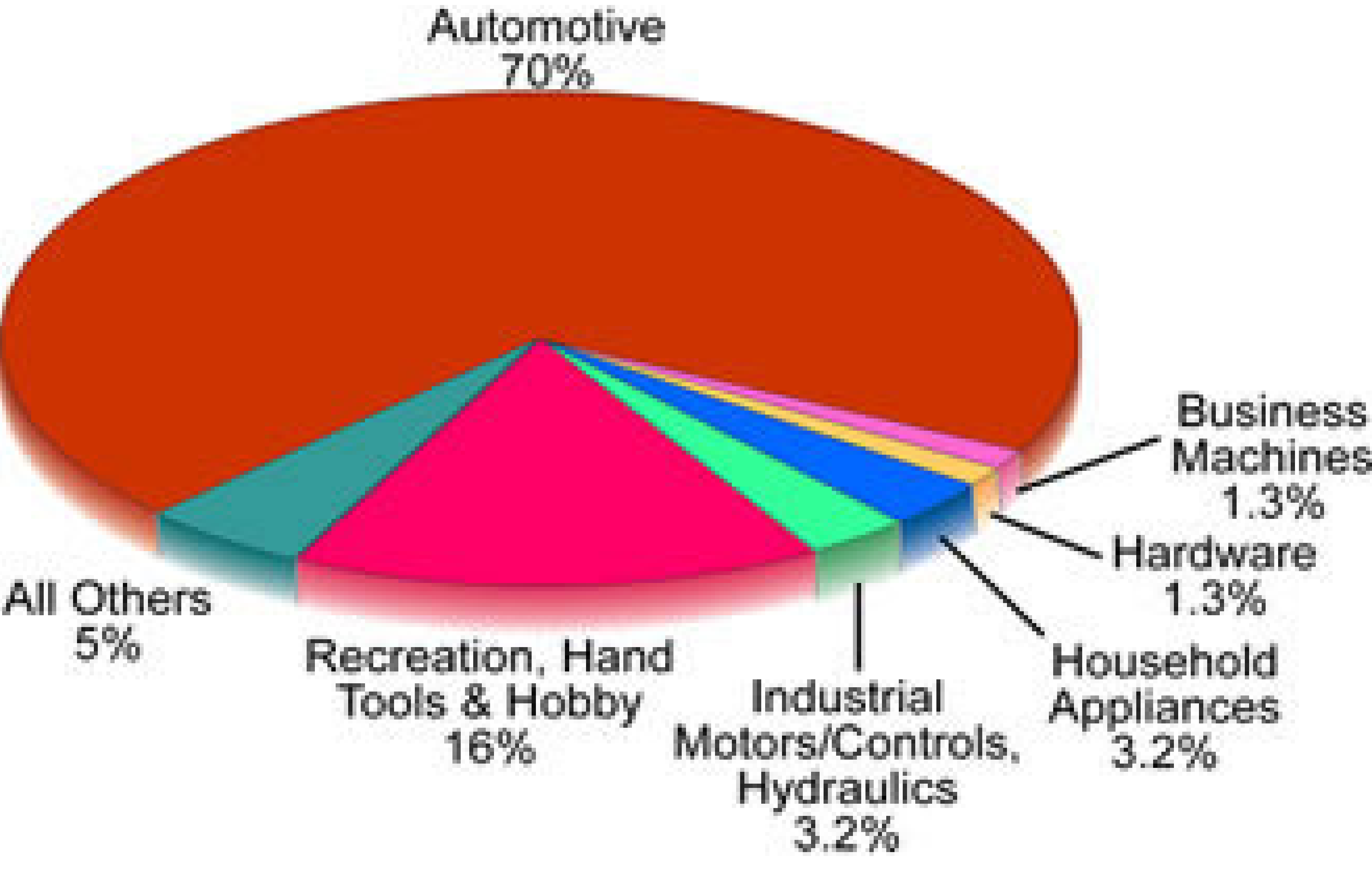
Material[a]	Form and Composition	Condition[b]	Percent of Theoretical Density	Tensile Strength		Elongation in 2 in. (%)
				10^3 psi	Mpa	
Iron	Wrought	HR	—	48	331	30
	P/M—49% Fe min	As sintered	89	30	207	9
	P/M—99% Fe min	As sintered	94	40	276	15
Steel	Wrought AISI 1025	HR	—	85	586	25
	P/M—0.25% C, 99.75% Fe	As sintered	84	34	234	2
Stainless steel	Wrought type 303	Annealed	—	90	621	50
	P/M type 303	As sintered	82	52	358	2
Aluminum	Wrought 2014	T6	—	70	483	20
	P/M 201 AB	T6	94	48	331	2
	Wrought 6061	T6	—	45	310	15
	P/M 601 AB	T6	94	36.5	252	2
Copper	Wrought OFHC	Annealed	—	34	234	50
	P/M copper	As sintered	89	23	159	8
		Repressed	96	35	241	18
Brass	Wrought 260	Annealed	—	44	303	65
	P/M 70% Cu-30% Zn	As sintered	89	37	255	26

[a]Equivalent wrought metal shown for comparison. [b]HR, hot rolled; T6, age hardened.

TABLE 18-6 Comparison of Four Powder Processing Methods

Characteristic	Conventional Press and Sinter	Metal Injection Molding (MIM)	Hot-Isostatic Pressing (HIP)	P/M Forging
Size of workpiece	Intermediate <5 pounds	Smallest <1/4 pounds	Largest 1–1000 pounds	Intermediate <5 pounds
Shape complexity	Good	Excellent	Very good	Good
Production rate	Excellent	Good	Poor	Excellent
Production quantity	>5000	>5000	1–1000	>10,000
Dimensional precision	Excellent ±0.001 in./in.	Good ±0.003 in./in.	Poor ±0.020 in./in.	Very good ±0.0015 in./in.
Density	Fair	Very good	Excellent	Excellent
Mechanical properties	80–90% of wrought	90–95% of wrought	Greater than wrought	Equal to wrought
Cost	Low \$0.50–5.00/lb	Intermediate \$1.00–10.00/lb	High >\$100.00/lb	Somewhat low \$1.00–5.00/lb

PM Structural Components Markets



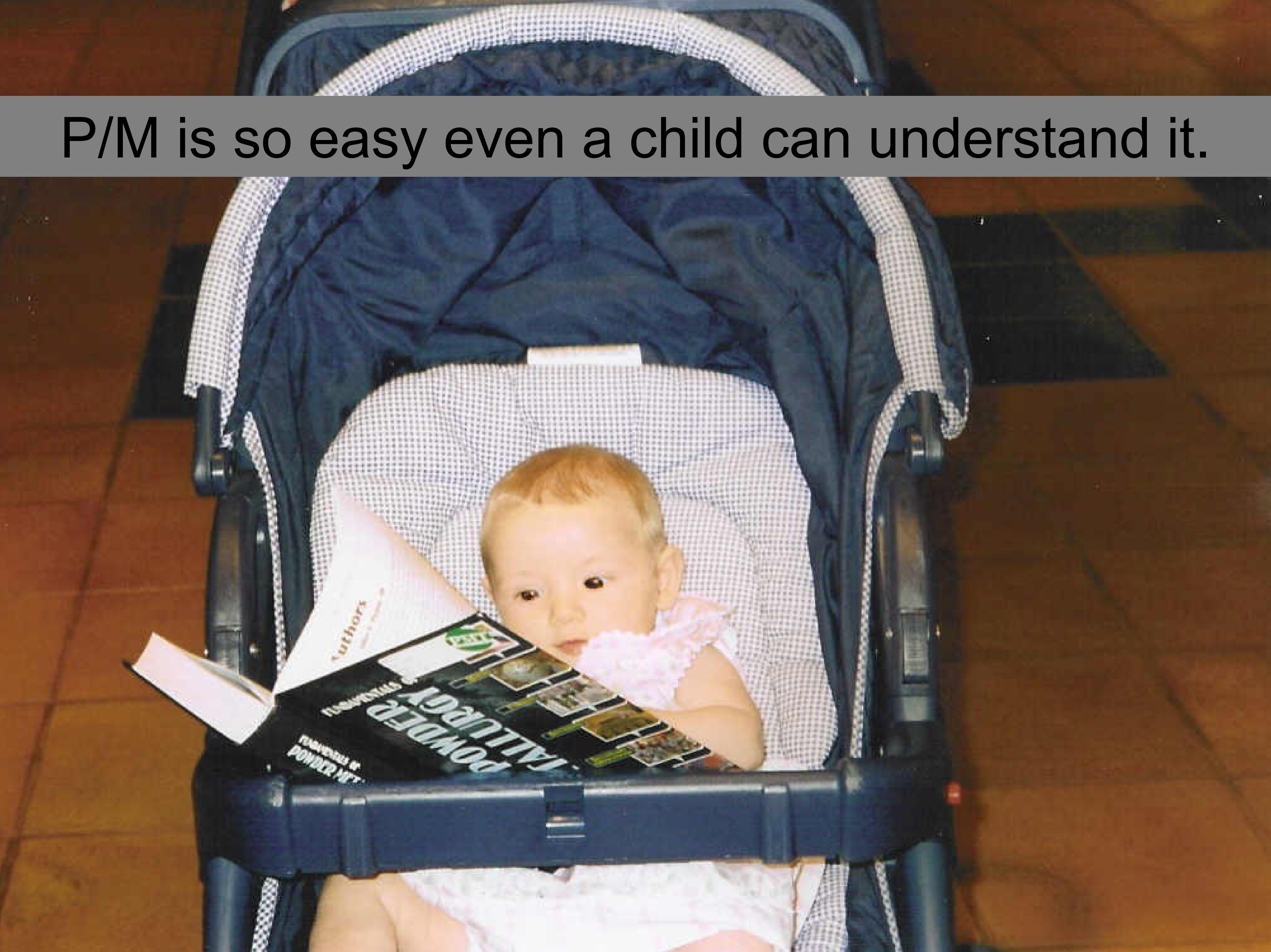
SUMMARY

- 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

CONCLUSIONS

- P/M is a proven technology dating back centuries.
- By utilizing 97% original material, cost and energy are minimized
- Properties and dimensions are easily controlled.
- Wide variety of P/M applications which are still increasing

P/M is so easy even a child can understand it.



REFERENCES

1. Manufacturing engineering & technology, Serope Kalpakjian & Steven R. Schimid, 4th edition, Pearson Education, Delhi
2. Introduction to physical metallurgy, Sidney H. Avner, 2nd edition, McGraw Hill, New York
3. Material Science & metallurgy, V. D. Kodgire, 5th edition, Everest publishing house, Pune
4. History of powder metallurgy, P. Ramakrishnan, Indian journal history of science, 18 (1), 109-114, 1983
5. Report on Aluminum powder metallurgy, B. Verlinden & L. Froyen, Belgium
6. Powder metallurgy parts manufacturing, 1997 economic census, manufacturing industry series
7. Development of high ceramic in PMRI PP, Dr. Baray S. G., powder metallurgy research institute, Republic of Belarus

REFERENCES

8. Powder metallurgy , Prof Onwubolu
9. New research trends in powder metallurgy, R. L. Orban, Romanian reports in physics, 56 (3), 505 – 516, 2004
10. Fundamental principles of powder metallurgy, Arnold publishers, London
11. Introduction to powder metallurgy, J. S. Hirshhorn
12. ASM metals handbook 7

THE END

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