Theory and Practice of Ceramic Processes

Lecture 6
Forming Processes:
Pressing

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AGH

SHAPE-FORMING PROCESSES

AIMS

- **to get optimal microstructure of a green body**
- **to get a shape as close as possible to the final one**

UNIFORM PARTICLE PACKING = OPTIMAL PORE SIZE DISTRIBUTION

Mechanical strength according to Griffith:

$$\sigma = Y \cdot \frac{K_{IC}}{\sqrt{a_C}}$$

Y **– geometrical factor,**
K_{Ic} – critical stress intensity factor,
a_c – critical flaw size.

Major Compaction Techniques Used for Ceramic Fabrication

Pressing
- Uniaxial
- Isostatic
- Hot pressing [a]
- Hot isostatic pressing [a]

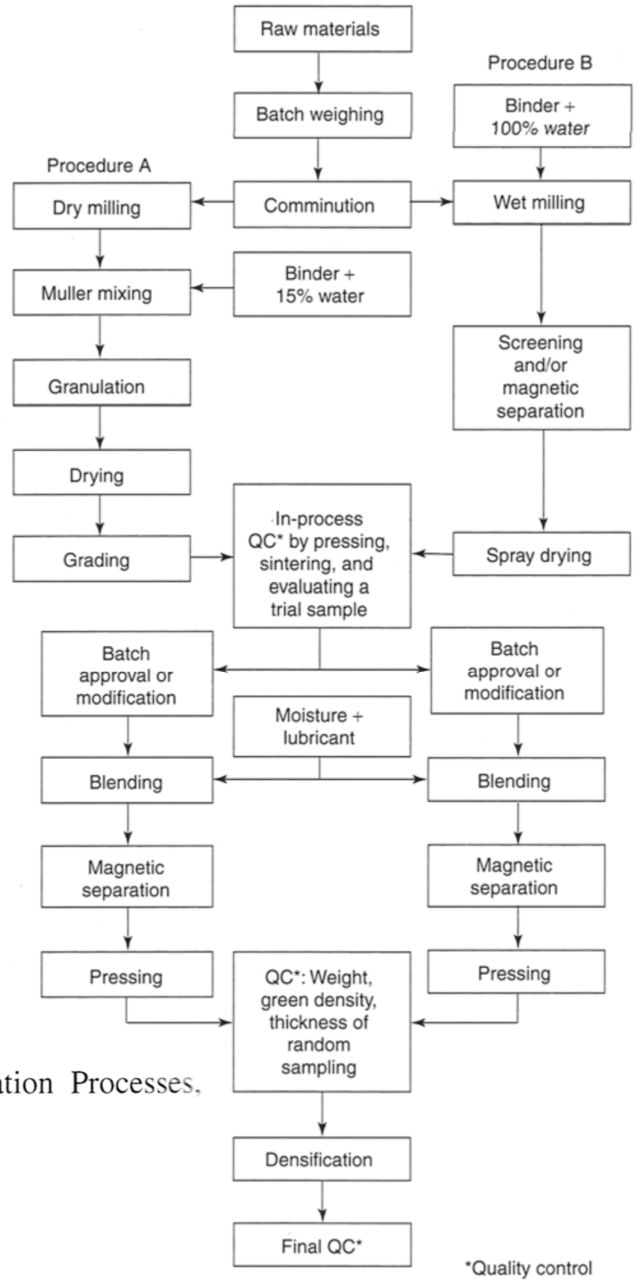
Slip Casting
- Drain casting
- Solid casting
- Vacuum casting
- Pressure casting
- Centrifugal casting
- Fugitive-mold casting
- Gel casting
- Electrophoretic deposition

Tape Casting
- Doctor blade
- Waterfall

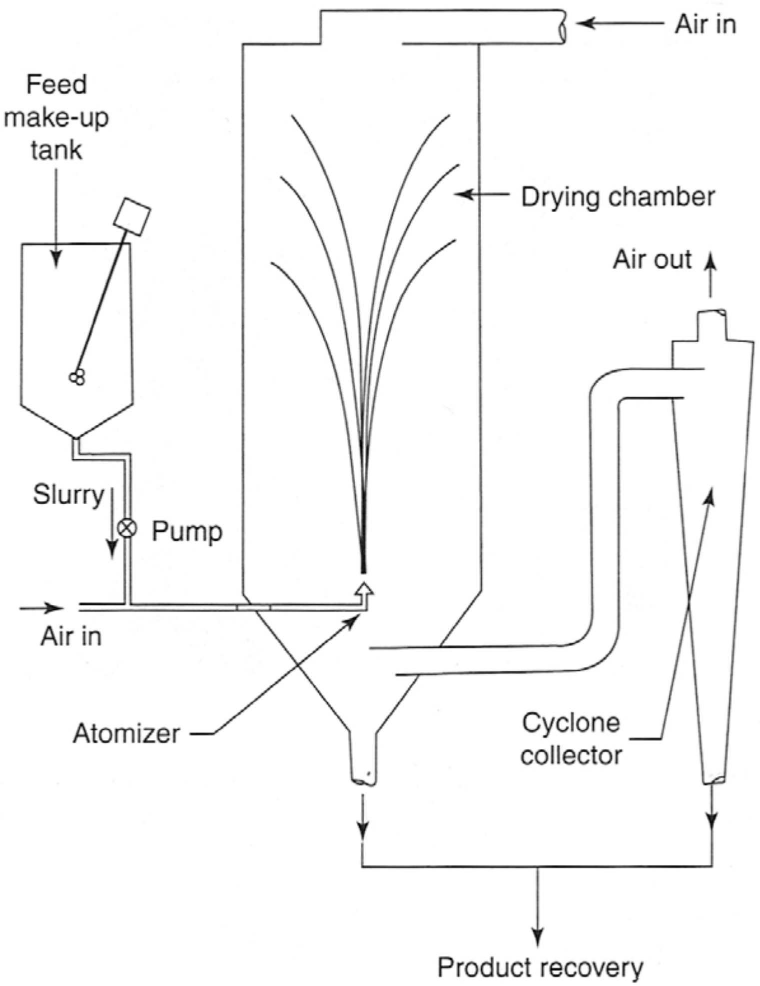
Plastic Forming
- Extrusion
- Roll forming
- Injection molding
- Compression molding

[a] Techniques that involve simultaneous compaction and densification and are discussed in Chapter 14.

PRESSING



Typical flow sheets for fabrication by pressing. (From Ceramic Fabrication Processes, Kingery, W.D., Ed., MIT Press, Cambridge, MA, 1963. With permission.)



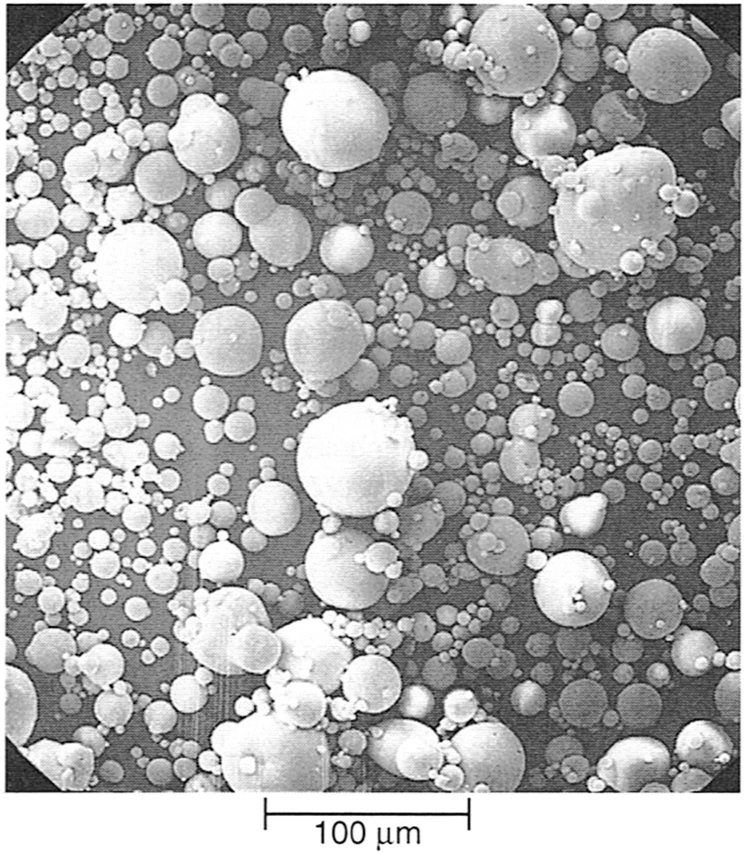
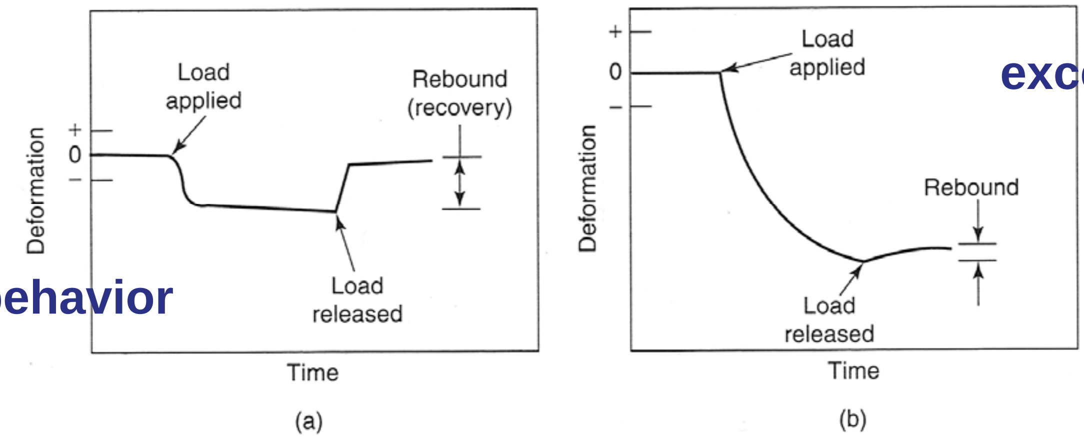


Photo taken with a scanning electron microscope showing the spherical morphology of spray-dried powder. (Courtesy of Ceramatec, Inc.)

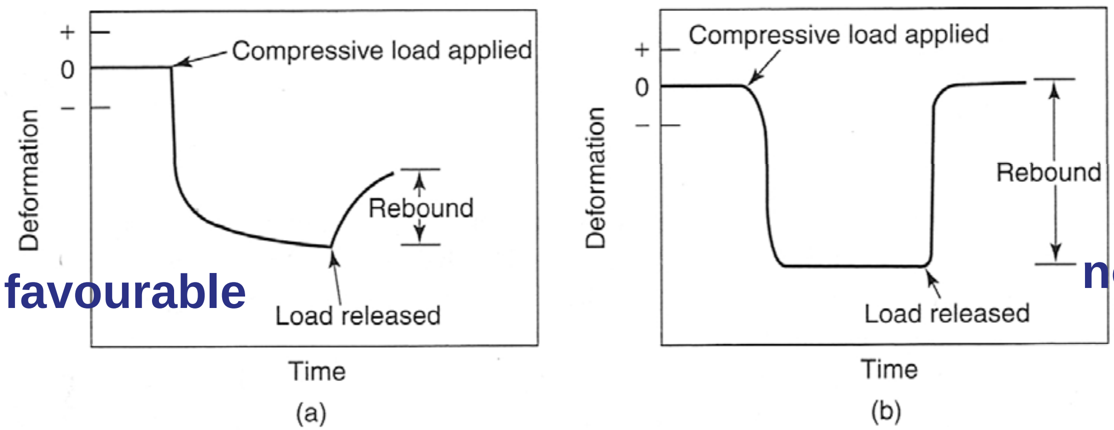
Schematic of one type of spray dryer. (Drawing courtesy of ASM International.)

ADDITIVES – Binders and Plasticizers



bad behavior **excelent behavior**

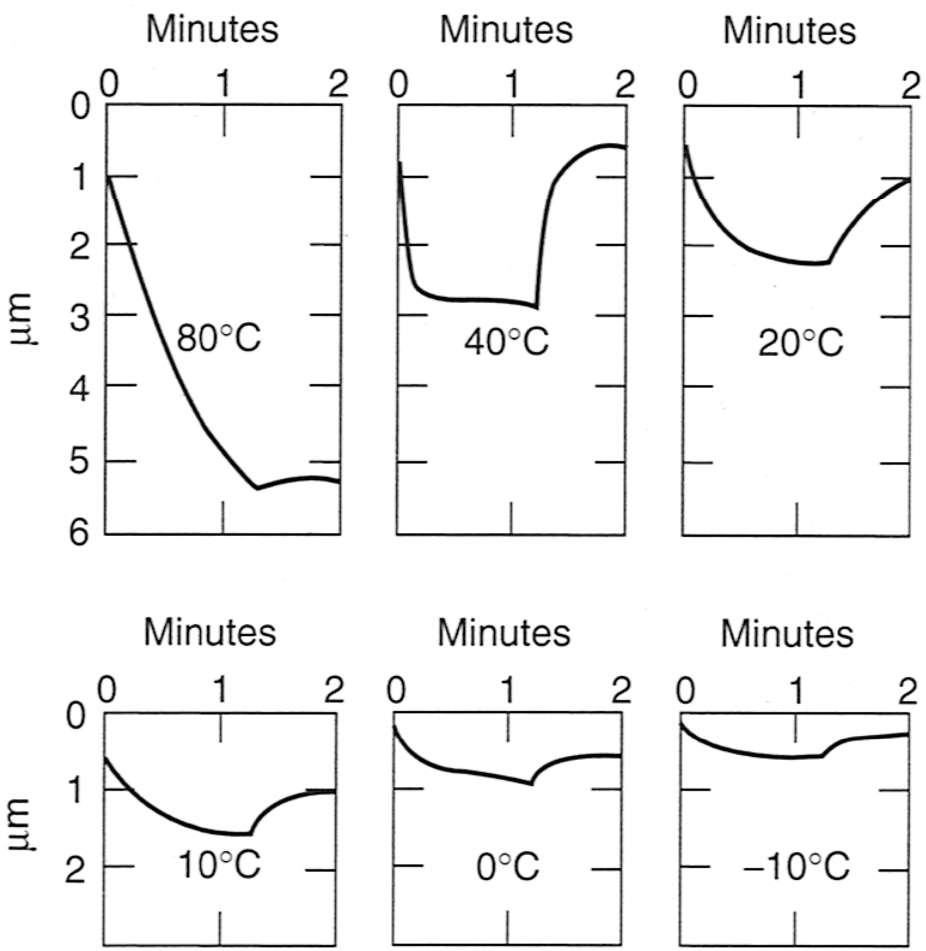
(a) Glassy deformation behavior below the glass transition temperature and (b) plastic behavior above the glass transition temperature. (Drawings courtesy of ASM International.)



rather favourable **not favorable**

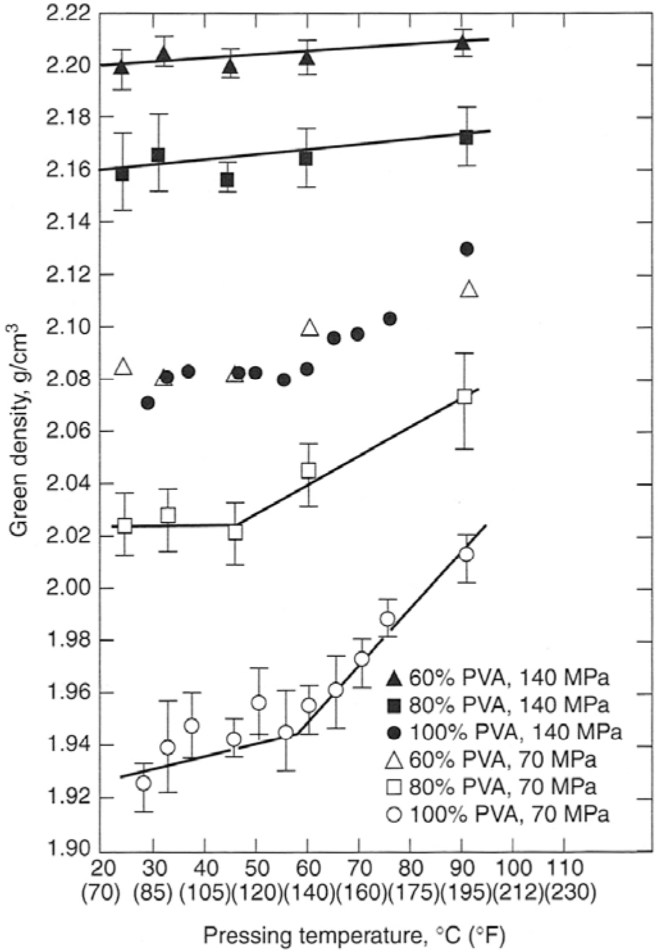
(a) Viscoelastic deformation behavior and (b) rubbery deformation behavior. (Drawings courtesy of ASM International.)

Dependence of deformation characteristics on temperature



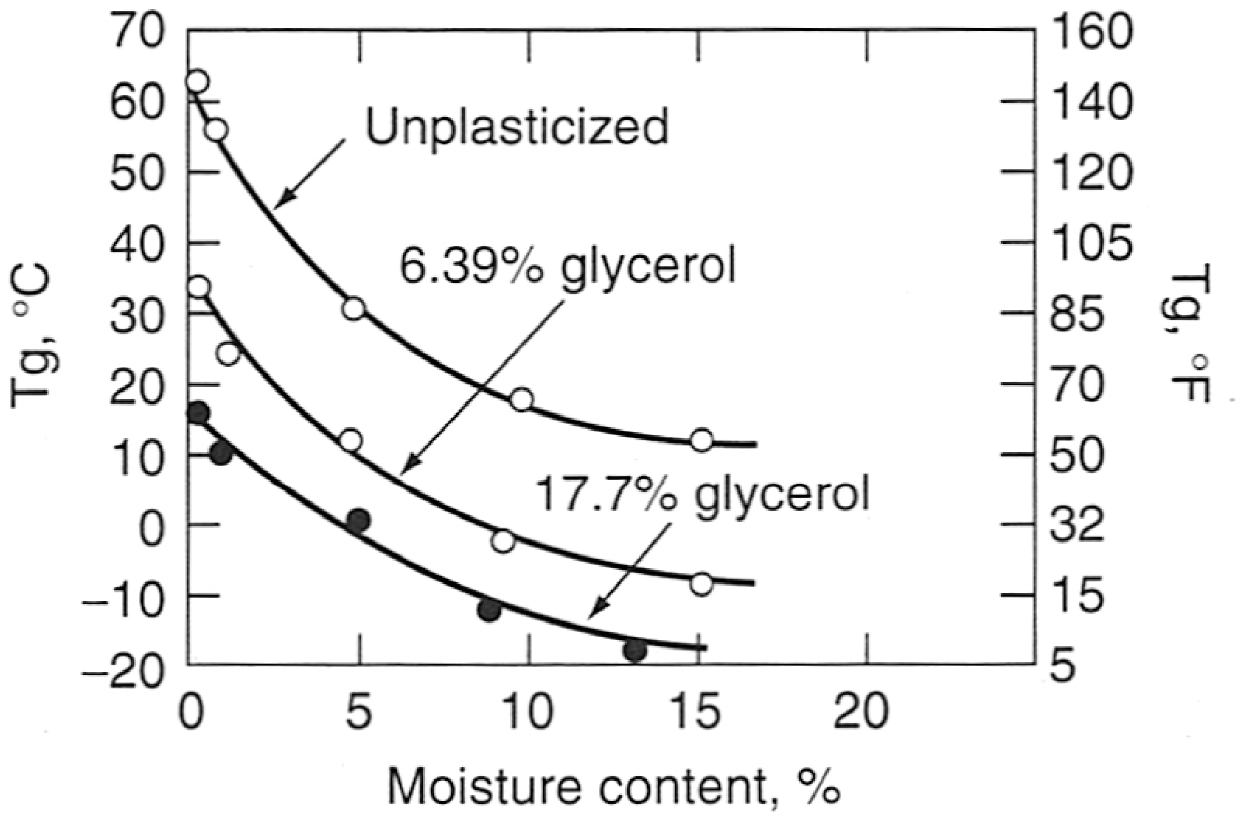
Deformation behavior of an alkyd organic binder at various temperatures showing transition from glassy to viscoelastic to rubbery to plastic. (Adapted from Rosen, S.L., *Fundamental Principles of Polymeric Materials*, Wiley, New York, 1982.)

Effect of pressing temperature and amount of plasticizer on green density



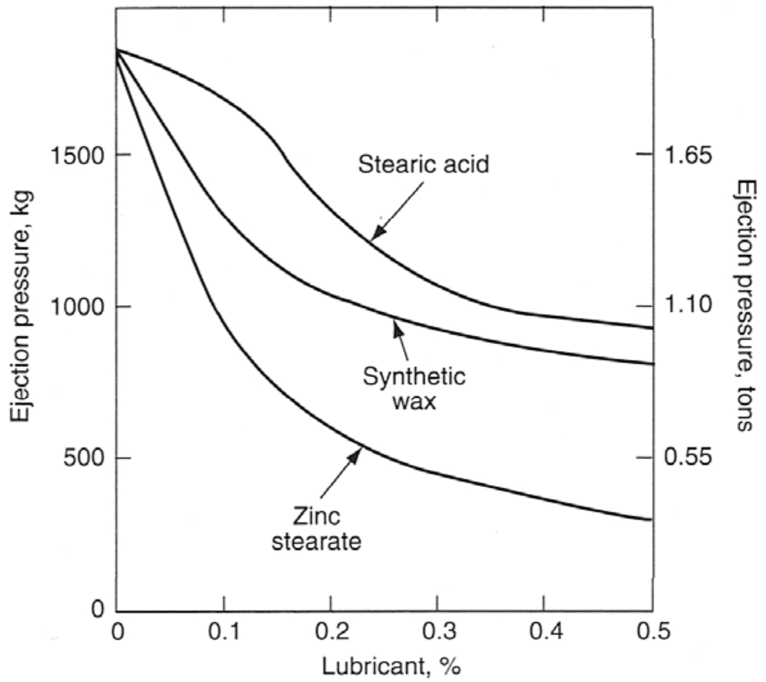
Green density of Al_2O_3 pressed with various ratios of polyvinyl alcohol (PVA) binder and polyethylene glycol (PEG) at different pressures and temperatures. (From Nies and Messing, *J. Am. Ceram. Soc.*, 301, 1984. With permission.)

Ductile-brittle transition in PVA



Effects of additions of glycerol and moisture on the glass transition temperature of a PVA binder. (From Nies and Messing, *J. Am. Ceram. Soc.*, 301, 1984. With permission.)

Lubricants and compaction aids



Effects of lubricants on decreasing die-wall friction and the pressure to eject a pressed part from a die. (Drawing courtesy of ASM International.)

Low-Shear-Strength Materials Used as Lubricants for Pressing

Zinc stearate	Paraffin
Stearic acid	Synthetic wax
Oleic acid	Lithium stearate
Oils	Potassium stearate
Naphthenic acid	Sodium stearate
Boric acid	Ammonium stearate
Boron nitride (hexagonal)	Magnesium stearate
Graphite	Talc

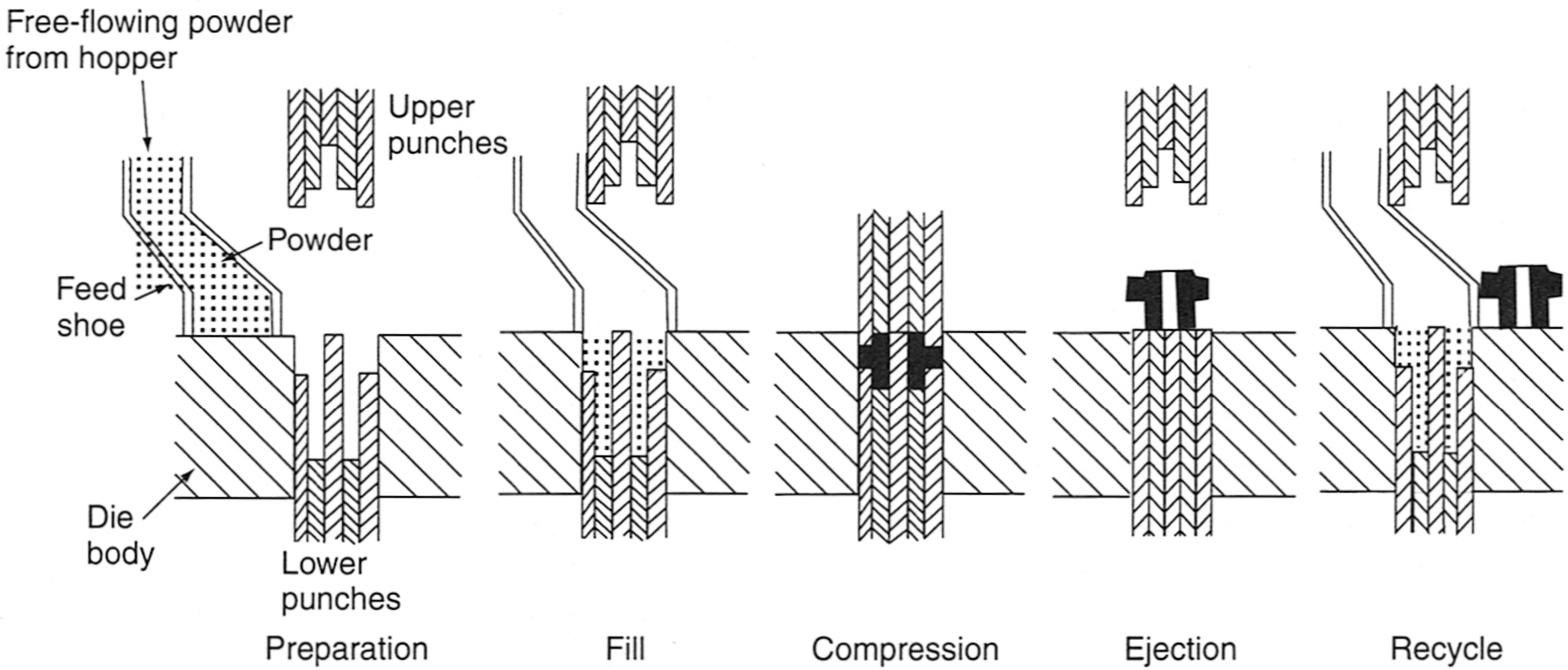
Use of Lubricants as Compaction Aids for Pressing of Al_2O_3[a]

Compaction Aid	Quantity, wt%	Green Density, g/cm³	Fired Density, g/cm³	Liner Shrinkage, %
None	0	2.53	3.85	13.1
Stearic acid	1.0	2.86	3.85	9.45
Stearic acid	2.0	3.00	3.89	8.27
Stearic acid	3.0	3.06	3.88	7.67
Oleic acid	2.0	2.97	3.90	8.63

[a] All specimens pressed at 34.5 MPa (5000 psi) and fired 1 h at 1700°C (3090°F).

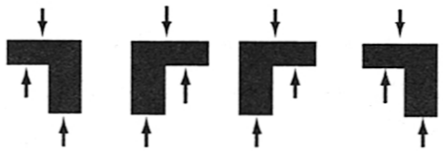
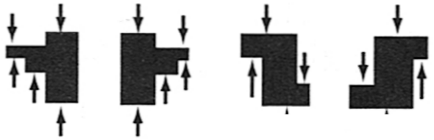
Source: Hart, L.D. and Hudson, L.K., *Am. Ceram. Soc. Bull.*, 43(1), 13, 1964.

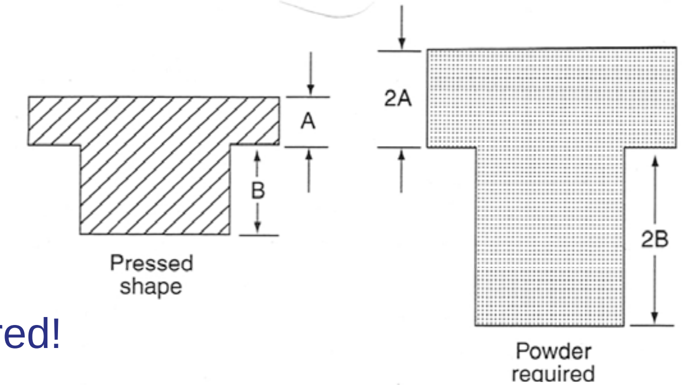
UNIAXIAL PRESSING



Schematic illustrating automated uniaxial pressing. (Adapted from Thurnauer, H., Controls required and problems encountered in production dry pressing, in *Ceramic Fabrication Processes,* Kingery, W.D., Ed., MIT Press, Cambridge, MA, 1963, pp. 62–70.)

Uniaxial Pressing Part and Tool Classifications

Class	Definition	Type of Tooling	Typical Part Cross Sections
I	Thin, one-level parts that can be pressed from one direction	Single action	
II	Thick, one-level parts that require pressing force from both ends	Double action	
III	Two-level parts that require pressing force from both ends	Double action, multiple motion	
IV	Multiple-level parts that require pressing force from both ends	Double action, multiple motion	



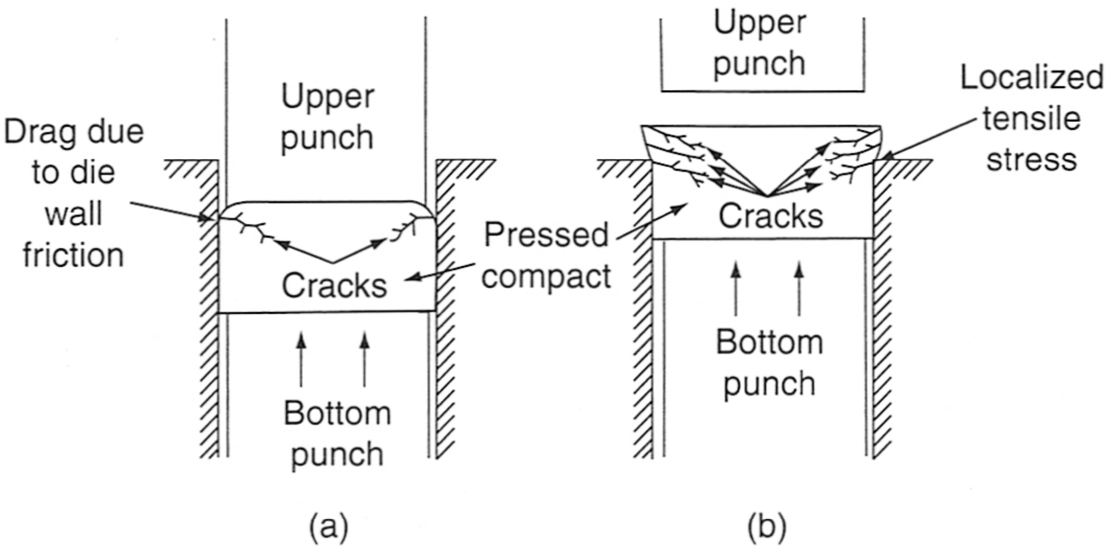
Two punches are required!

Schematic illustrating the different distances a punch must move to accomplish uniform compaction of the powder. Based on a powder with a compaction ratio of 2:1. (Drawing courtesy of ASM International.)

Dry pressing – 0-4% moisture
Wet pressing – 10-15% moisture

Uniaxial pressing problems →

improper density or size
die wear
cracking
density variation.

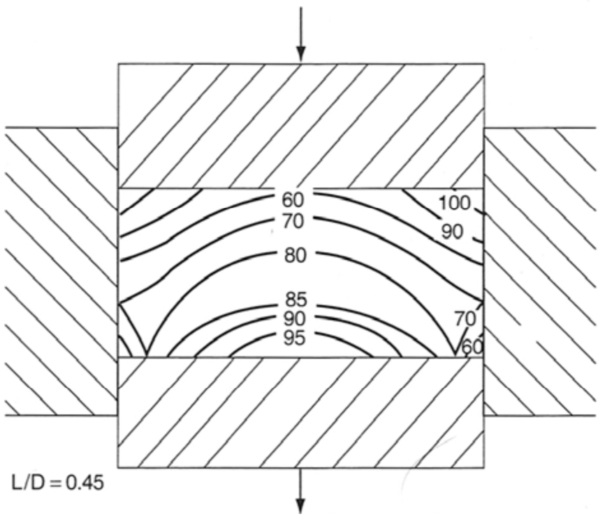


Mechanism of formation of laminar cracks in uniaxially pressed parts. (a) Pressure being released from upper punch and (b) material rebound at top of die. (Drawing courtesy of ASM International.)

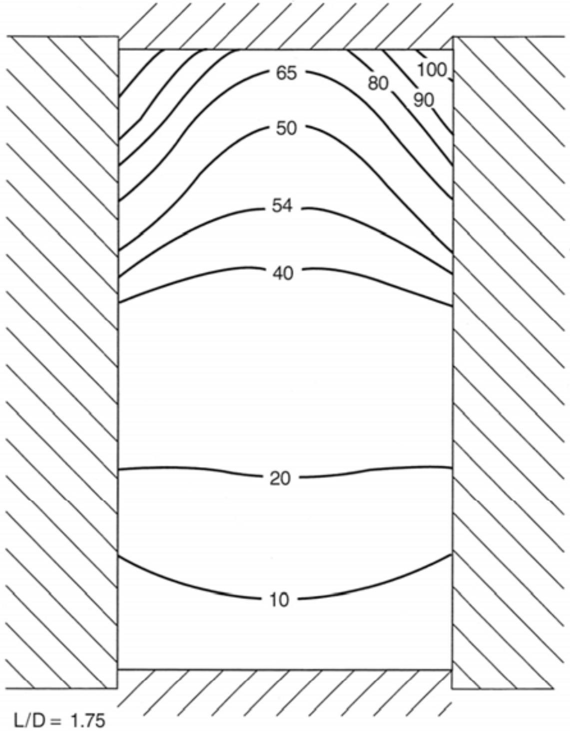
NONUNIFORM DENSIFICATION

Sources:

1. the friction between the powder and the die wall, and between powder particles
2. nonuniform fill of the die
3. the presence of hard agglomerates



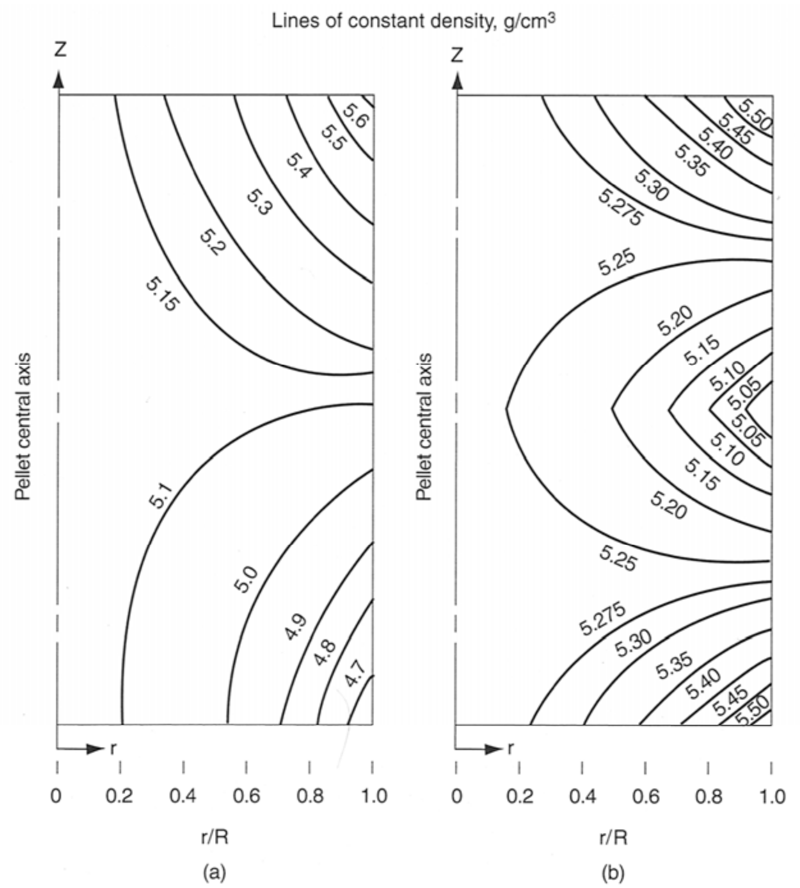
(a) L/D = 0.45



(b) L/D = 1.75

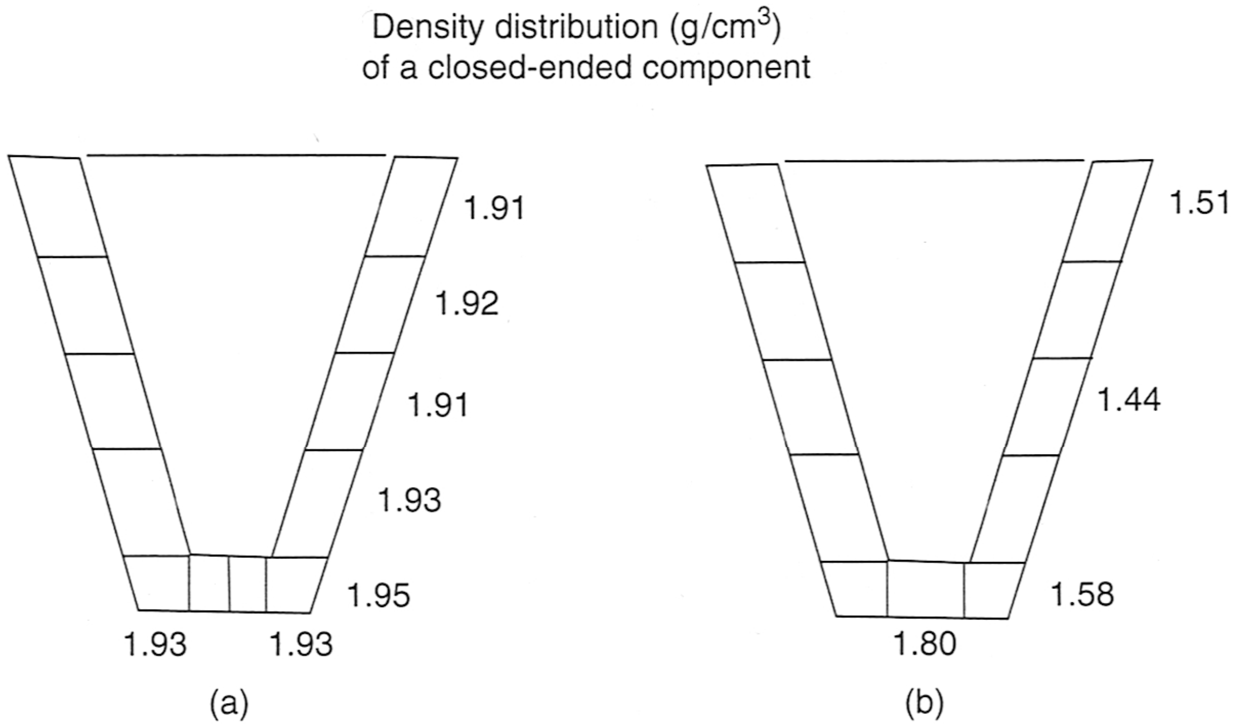
Pressure variations in uniaxial pressing due to die-wall friction and particle-particle friction, which lead to nonuniform density of the pressed compact. (Adapted from *Ceramic Fabrication Processes*, Kingery, W.D., Ed., MIT Press, Cambridge, MA, 1963.)

Effect of two-side pressing

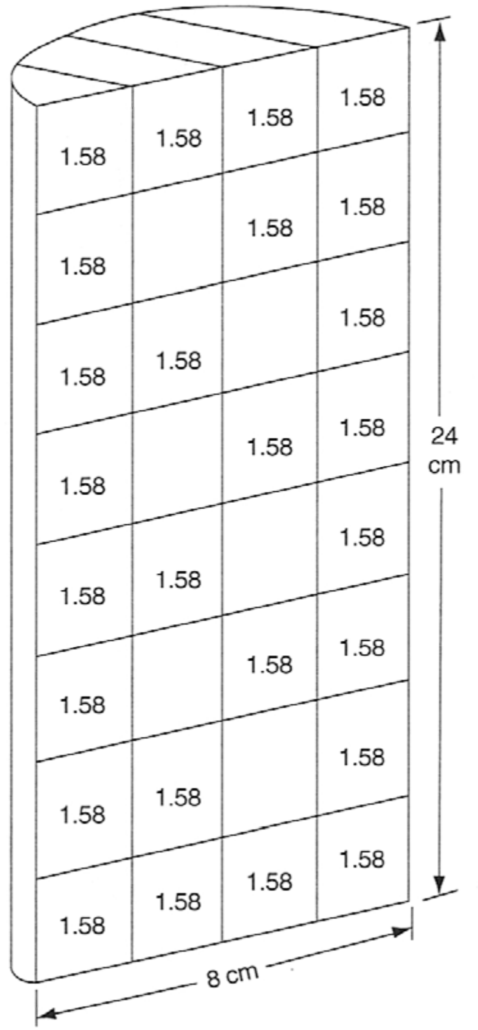


Decrease in pressure curves and increase in uniformity of green density by pressing compact from opposing directions with a double-acting press. (a) Single-acting press and (b) double-acting press. (From Thompson, R.A., *Am. Ceram. Soc. Bull.*, 60(2), 237–243, 1981. With permission.)

Effect of isostatic pressing

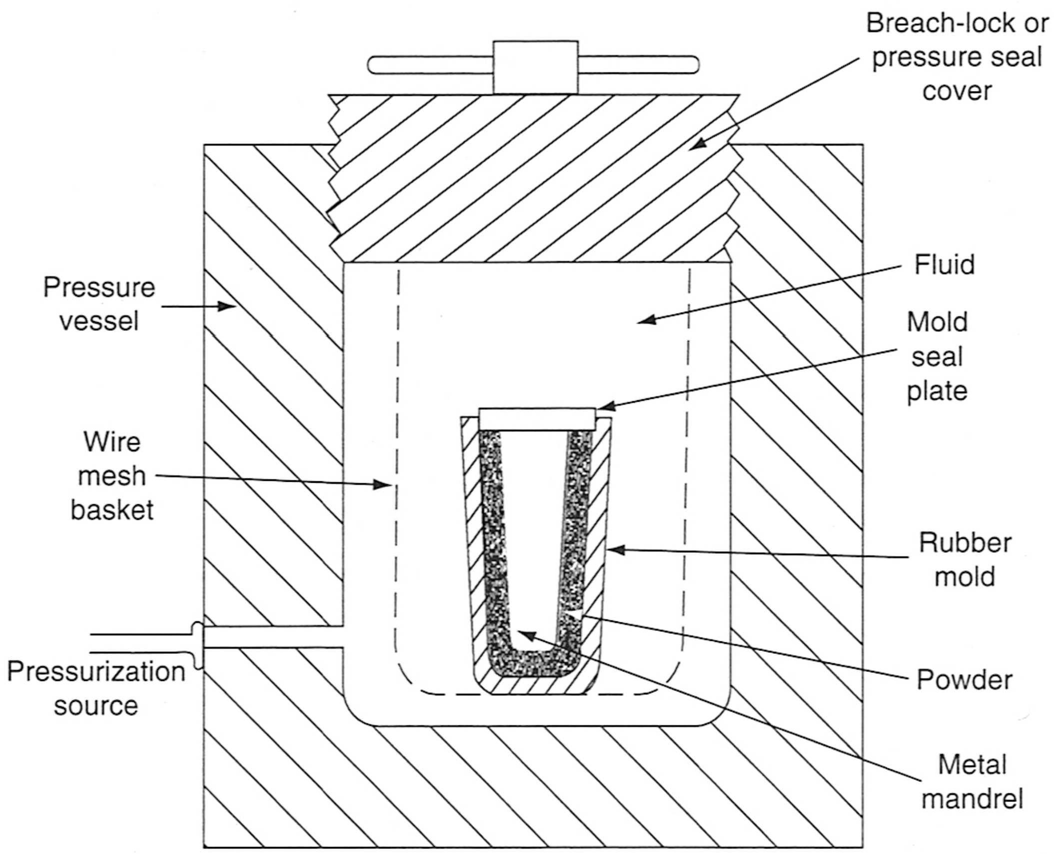


Improvement in green density uniformity of a thin-wall crucible achieved by isostatic pressing. (a) After isostatic pressing and (b) after die pressing. (From Gill, R.M. and Bryne, J., in *Science of Ceramics*, Vol. 4, Stewart, G.H., Ed., British Ceramic Research Association, London, 1968. With permission.)



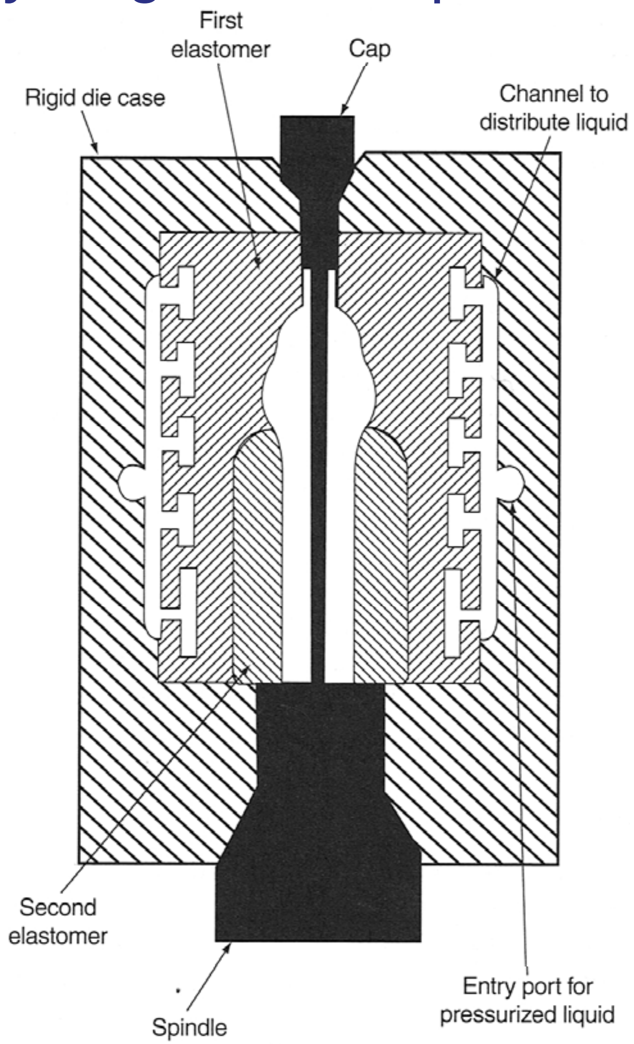
Density uniformity achieved in a large, solid cylinder by isostatic pressing. (From Gill, R.M. and Bryne, J., in *Science of Ceramics*, Stewart, G.H., Ed., British Ceramic Research Association, London, 1968. With permission.)

Wet-Bag Isostatic Pressing

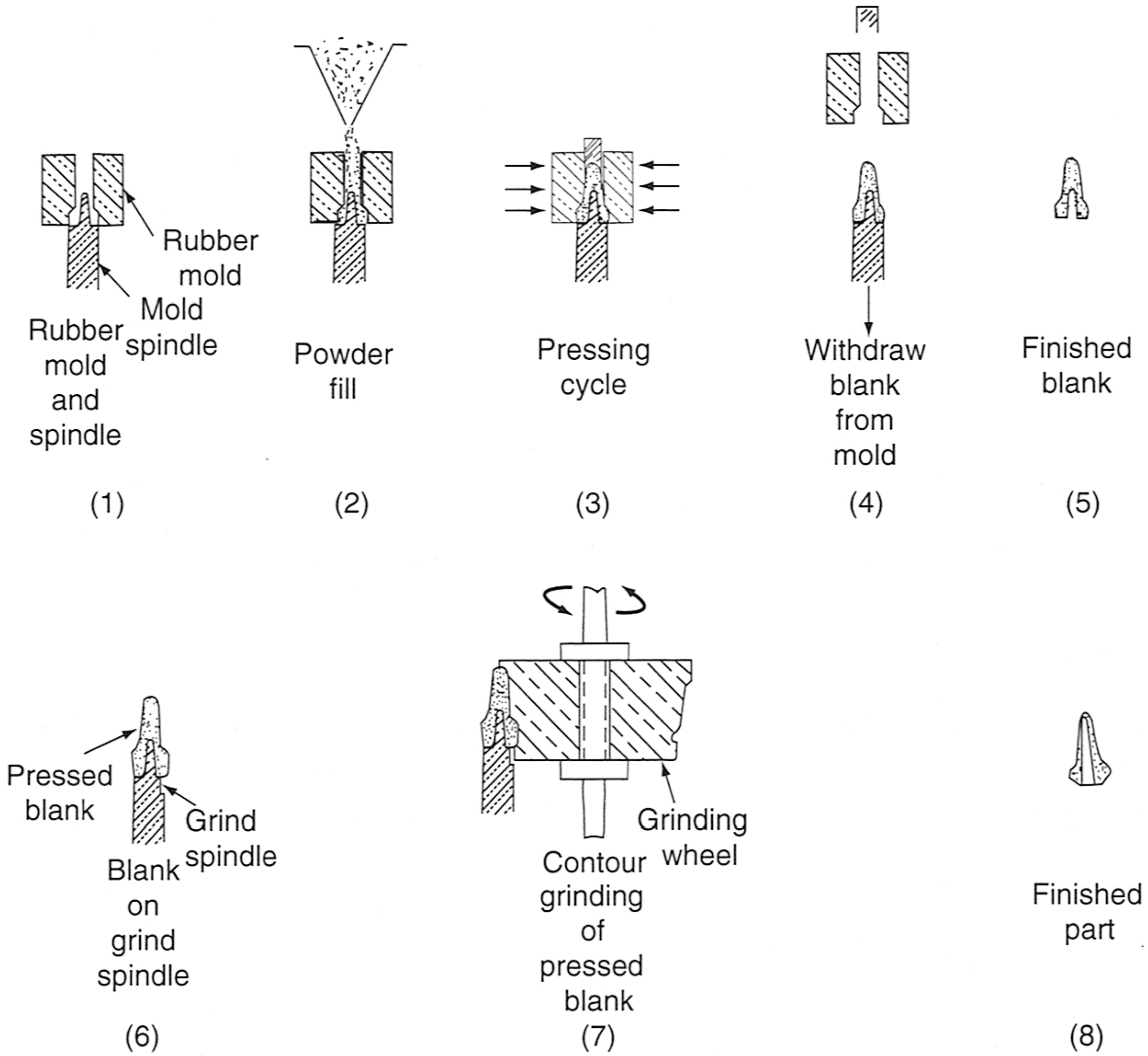


Schematic of a wet-bag isostatic pressing system. (© Drawing courtesy of ASM International.)

Dry-bag isostatic pressing

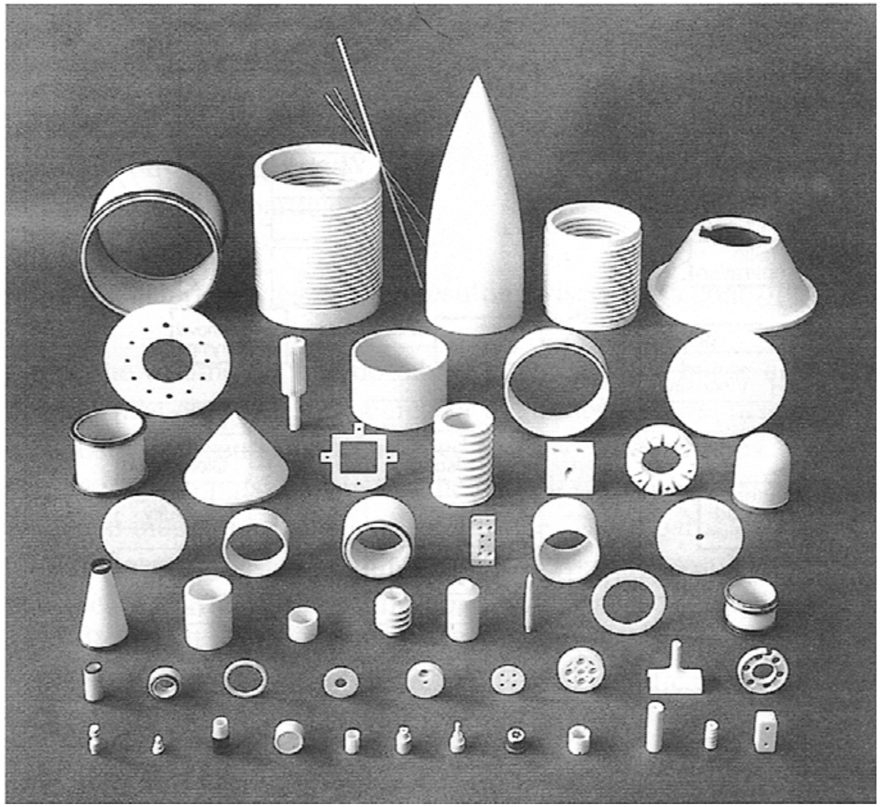


Schematic of a die for dry-bag isostatic pressing of a spark plug insulator. (Drawing courtesy of ASM International.)



Automated dry-bag isostatic pressing and formed-wheel green machining of a zirconia electrolyte for an automotive oxygen sensor. (Drawings courtesy of ASM International.)

APPLICATION OF PRESSING



Ceramic parts formed by uniaxial and isostatic pressing, some with green machining. (Courtesy of Western Gold and Platinum Company, Subsidiary of GTE Sylvania, Inc.)

Thank you for your kind attention