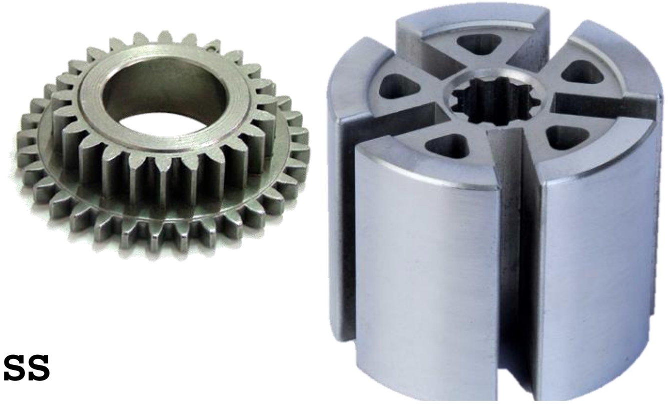
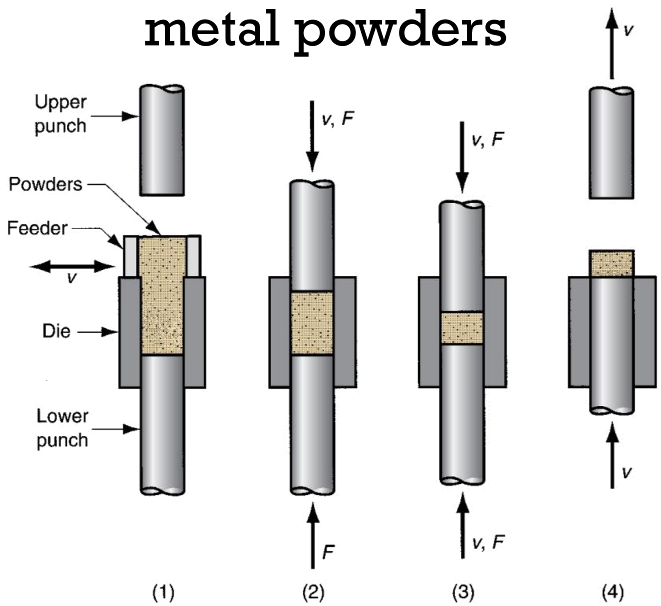
Mechanics In Design and Manufacturing

+ Powder Metallurgy

What is PM?



- Forming of objects from metal powders



- Process

1.
2.
3.
4.
5.

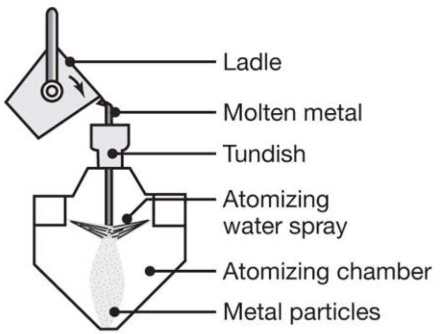
- Process Video

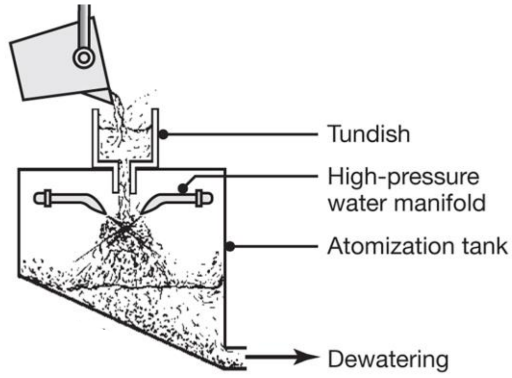
Why PM?

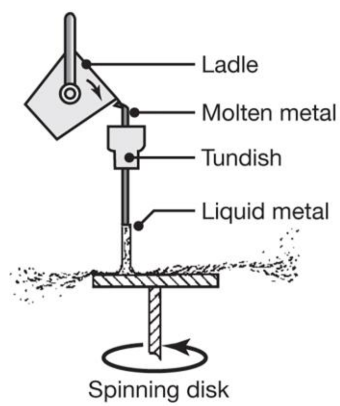
Advantages

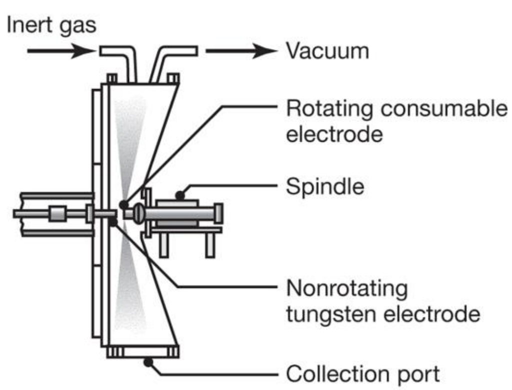
Disadvantages

Powder Production







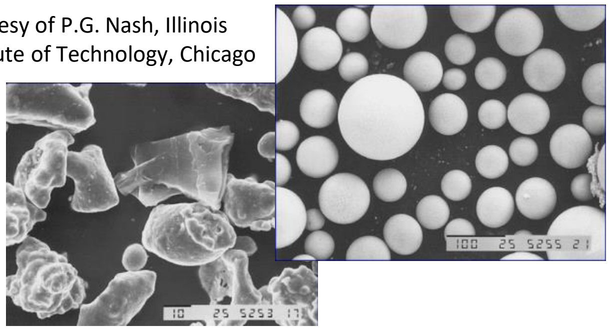


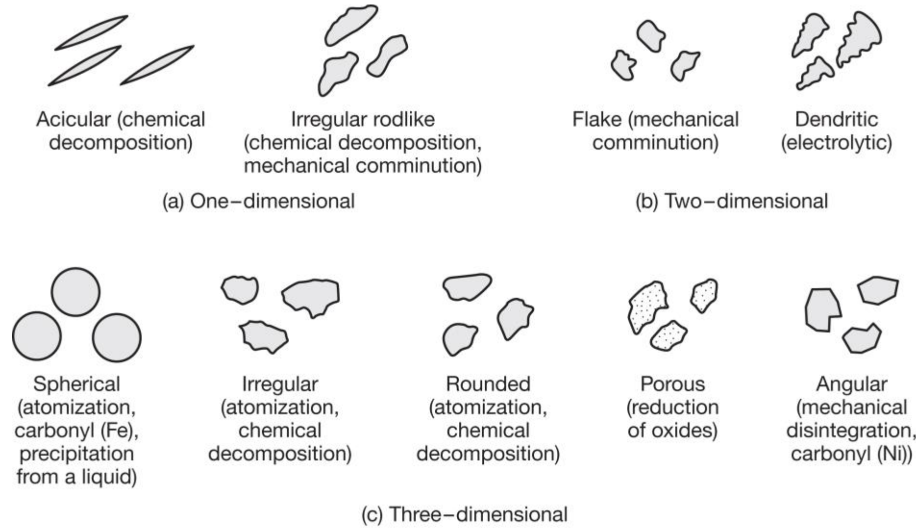
- Other Processes

Characterization

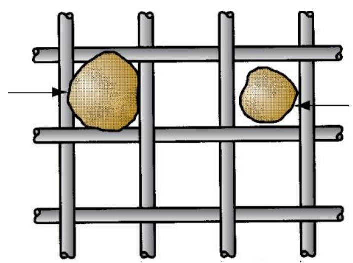
- Particle size/aspect ratio

Courtesy of P.G. Nash, Illinois Institute of Technology, Chicago

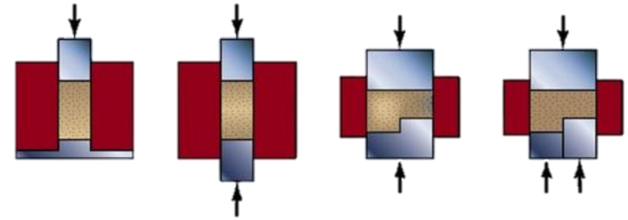


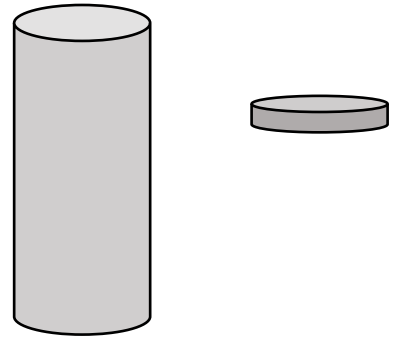


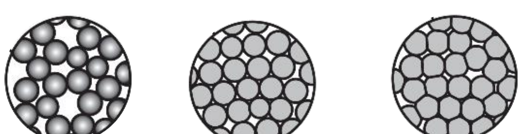
- Mesh



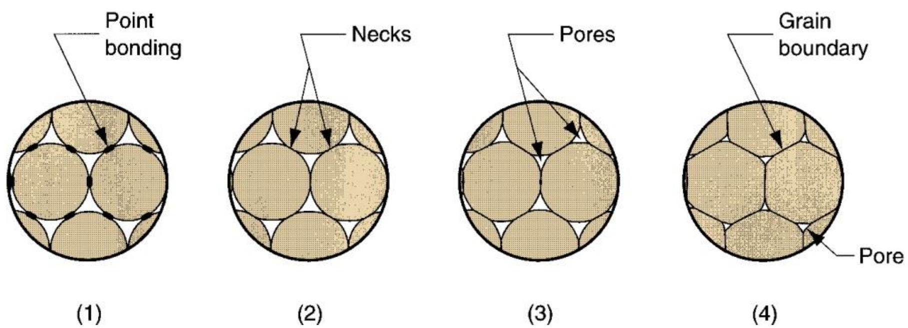
Pressing/Density







Sintering/Properties

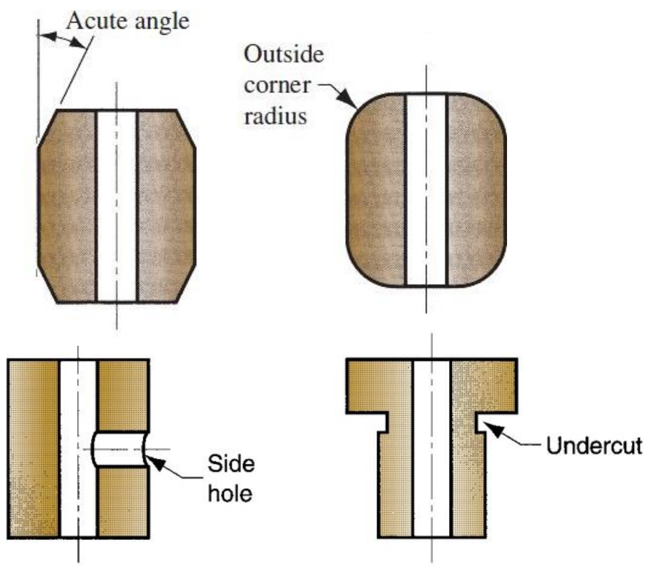


Groover 6th ed.

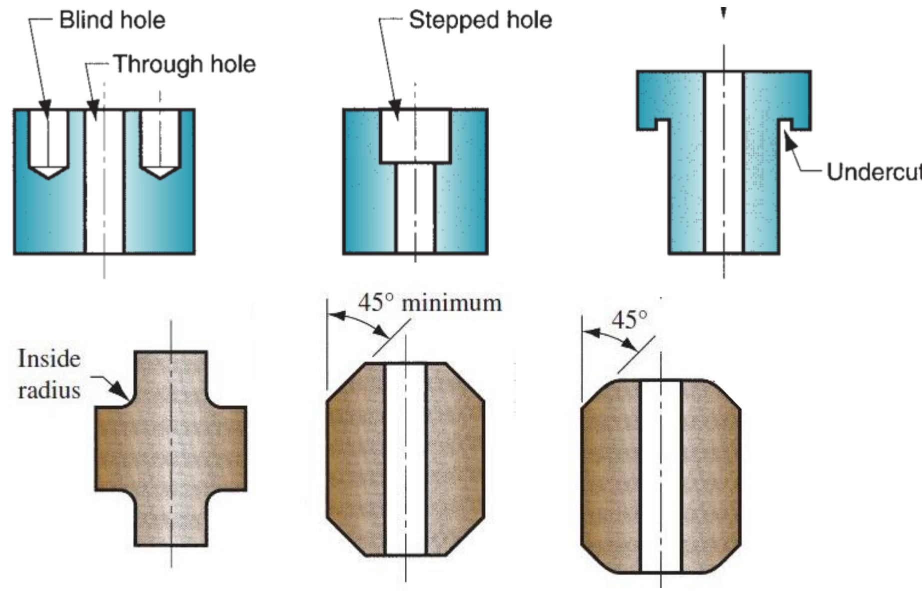
	Sintering Temperatures		
Metal	°C	°F	Typical Time
Brass	850	1600	25 min
Bronze	820	1500	15 min
Copper	850	1600	25 min
Iron	1100	2000	30 min
Stainless steel	1200	2200	45 min
Tungsten	2300	4200	480 min

Design Considerations

Features to Avoid



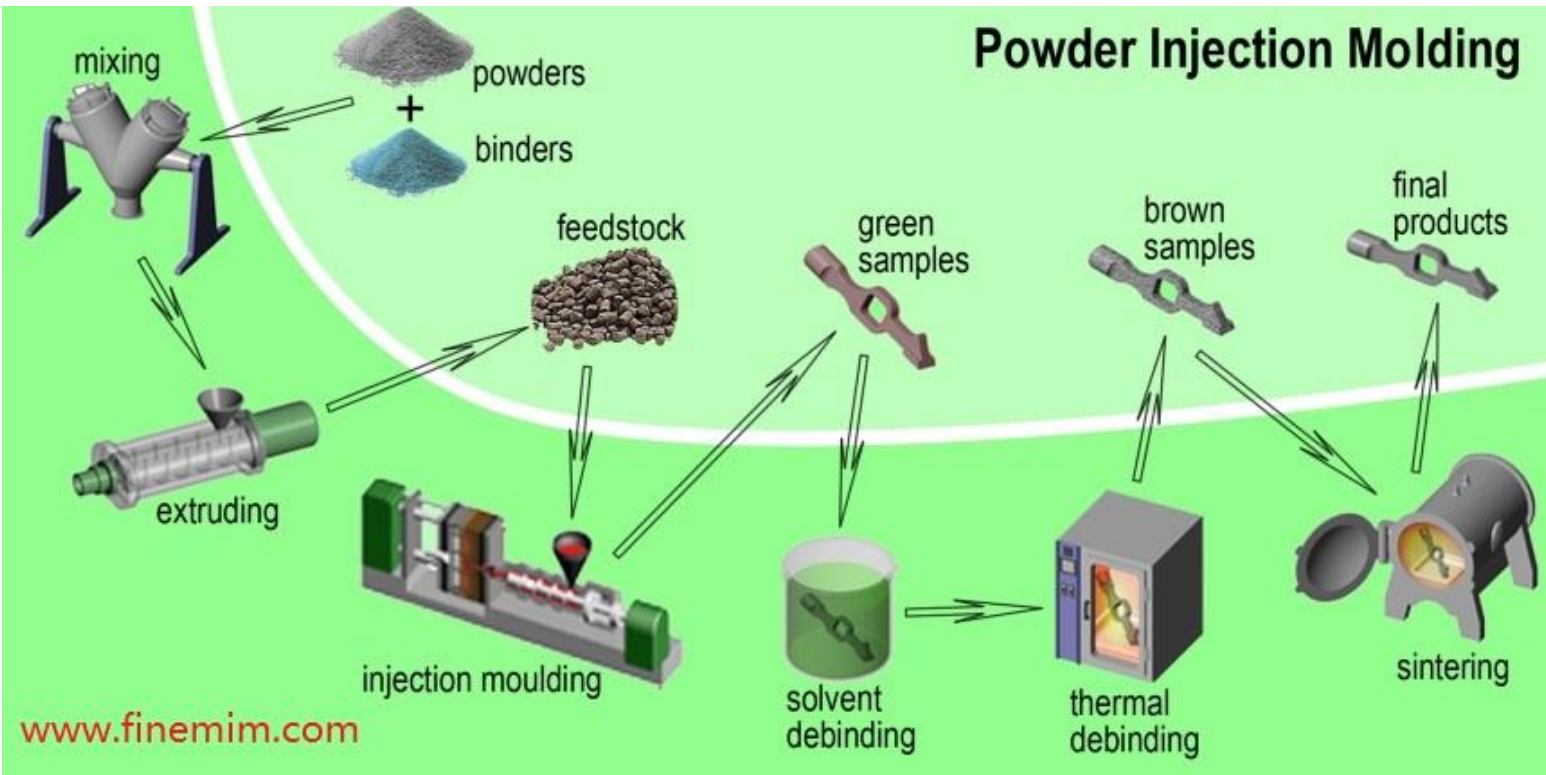
Permissible Features



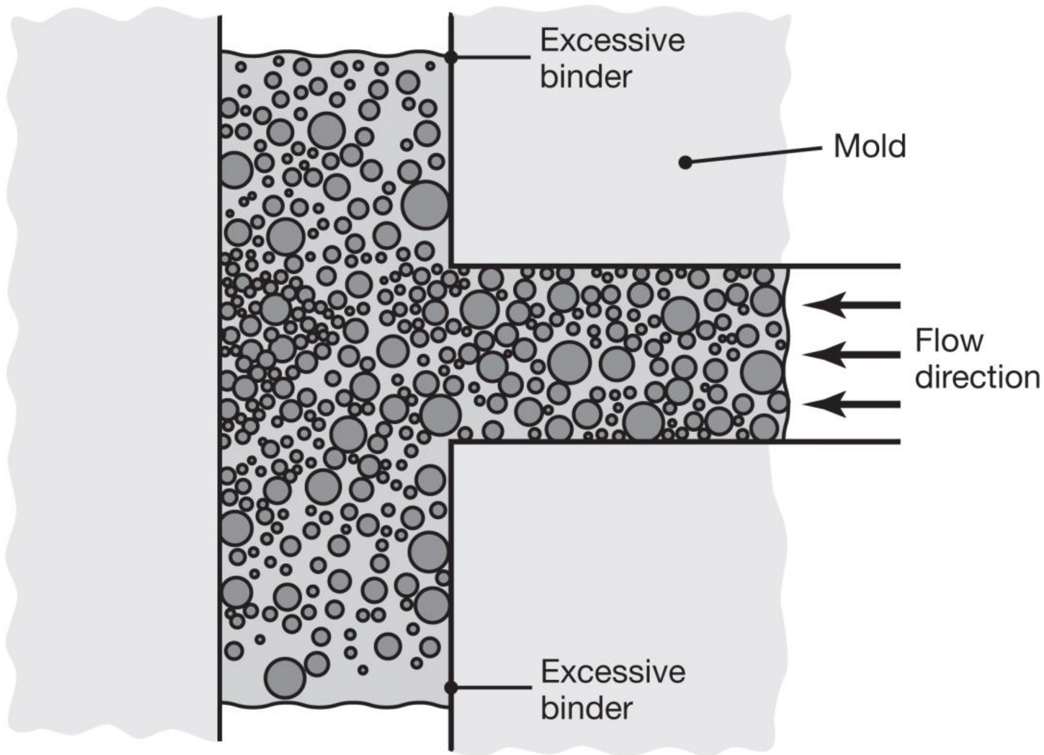
- Additional Notes

Metal Injection Molding

- A mixture of binder and metal powder is injected into a mold



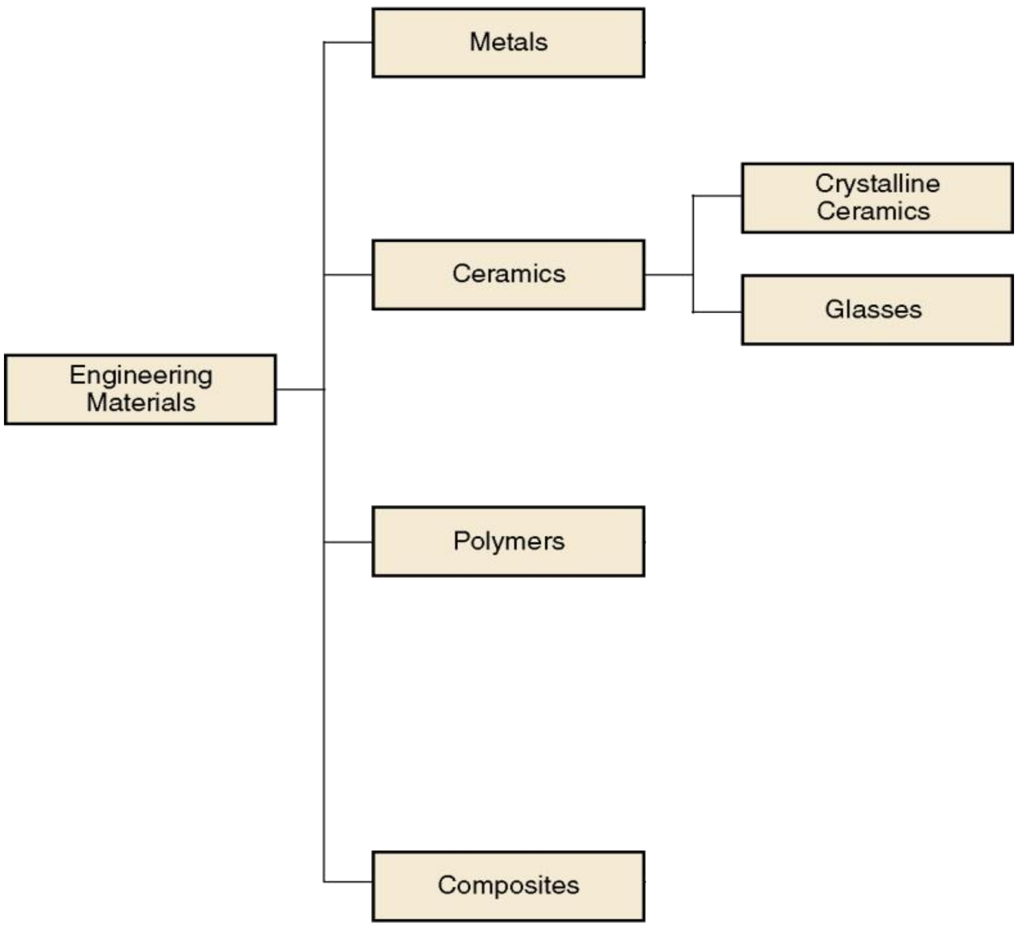
Design Considerations



Mechanics In Design and Manufacturing

+ Property and Behavior: Ceramics

Materials

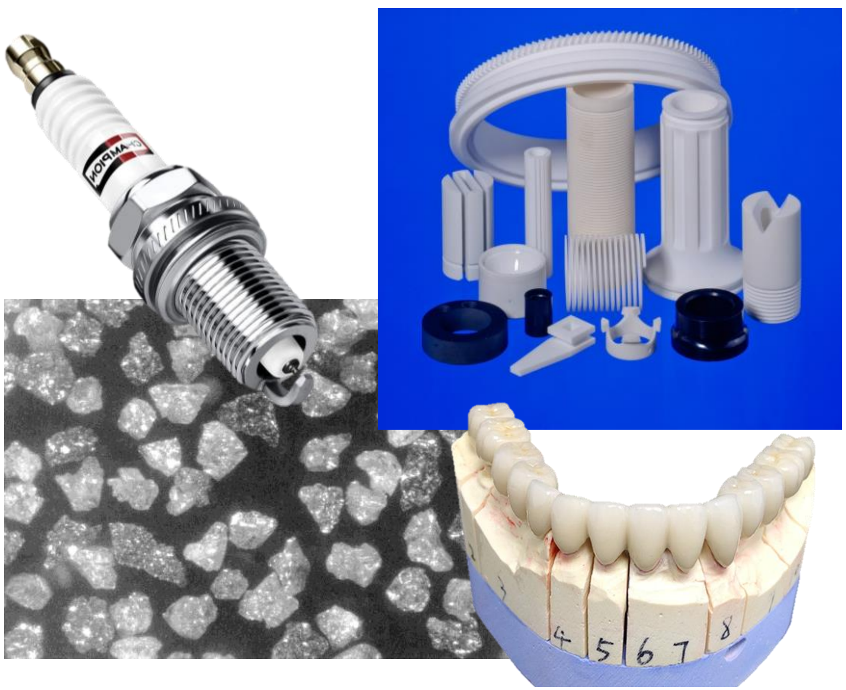


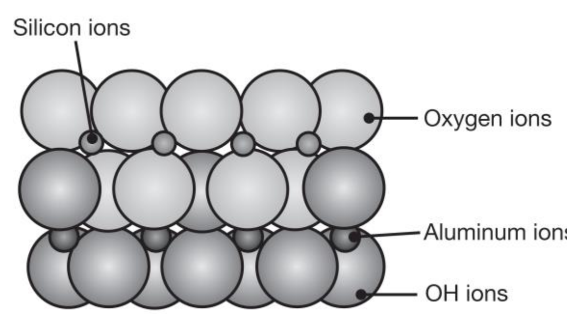
Metals
Crystalline Ceramics
Ceramics
Glasses
Engineering Materials
Polymers
Composites

What is a Ceramic?

- Inorganic compound consisting of a metal and one or more nonmetals

- Examples:





Physical Properties

High

Low

Material	Vickers Hardness (GPa)
Diamond (carbon)	130
Boron carbide (B_4C)	44.2
Aluminum oxide (Al_2O_3)	26.5
Silicon carbide (SiC)	25.4
Tungsten carbide (WC)	22.1
Silicon nitride (Si_3N_4)	16.0
Zirconia (ZrO_2) (partially stabilized)	11.7
Soda-lime glass	6.1

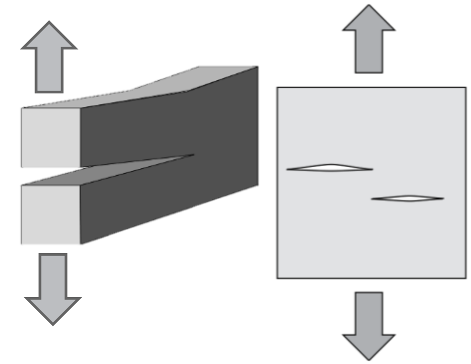
Adapted from *Callister 8e.*

Other properties

Material	Symbol	Transverse rupture strength (MPa)	Compressive strength (MPa)	Elastic modulus (GPa)	Hardness (HK)	Density (kg/m^3)
Aluminum oxide	Al_2O_3	140–240	1000–2900	310–410	2000–3000	4000–4500
Cubic boron nitride	cBN	725	7000	850	4000–5000	3480
Diamond	—	1400	7000	830–1000	7000–8000	3500
Silica, fused	SiO_2	—	1300	70	550	—
Silicon carbide	SiC	100–750	700–3500	240–480	2100–3000	3100
Silicon nitride	Si_3N_4	480–600	—	300–310	2000–2500	3300
Titanium carbide	TiC	1400–1900	3100–3850	310–410	1800–3200	5500–5800
Tungsten carbide	WC	1030–2600	4100–5900	520–700	1800–2400	10,000–15,000
Partially stabilized zirconia	PSZ	620	—	200	1100	5800

Note: These properties vary widely, depending on the condition of the material.

Failure of brittle ceramics



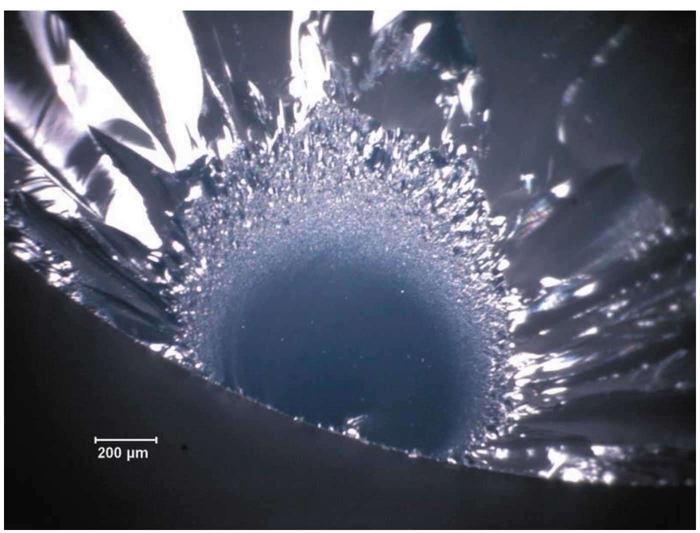
- Ceramics fail by the formation and propagation of cracks

Table 8.1 Room-Temperature Yield Strength and Plane Strain Fracture Toughness Data for Selected Engineering Materials

	Yield Strength		K_{Ic}	
Material	***MPa***	***ksi***	$MPa\sqrt{m}$	$ksi\sqrt{in.}$
	Metals			
Aluminum alloy[a] (7075-T651)	495	72	24	22
Aluminum alloy[a] (2024-T3)	345	50	44	40
Titanium alloy[a] (Ti-6Al-4V)	910	132	55	50
Alloy steel[a] (4340 tempered @ 260°C)	1640	238	50.0	45.8
Alloy steel[a] (4340 tempered @ 425°C)	1420	206	87.4	80.0
	Ceramics			
Concrete	—	—	0.2–1.4	0.18–1.27
Soda-lime glass	—	—	0.7–0.8	0.64–0.73
Aluminum oxide	—	—	2.7–5.0	2.5–4.6
	Polymers			
Polystyrene (PS)	25.0–69.0	3.63–10.0	0.7–1.1	0.64–1.0
Poly(methyl methacrylate) (PMMA)	53.8–73.1	7.8–10.6	0.7–1.6	0.64–1.5
Polycarbonate (PC)	62.1	9.0	2.2	2.0

[a] **Source:** Reprinted with permission, *Advanced Materials and Processes,* ASM International, © 1990.

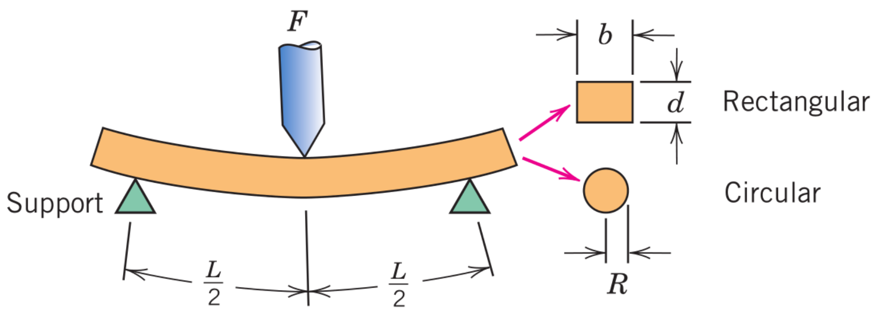
Adapted from *Callister 8e.*



Adapted from *Callister 8e.*

Flexural Strength

- Most ceramics are tested in flexure



$$\sigma = \text{stress} = \frac{Mc}{I}$$

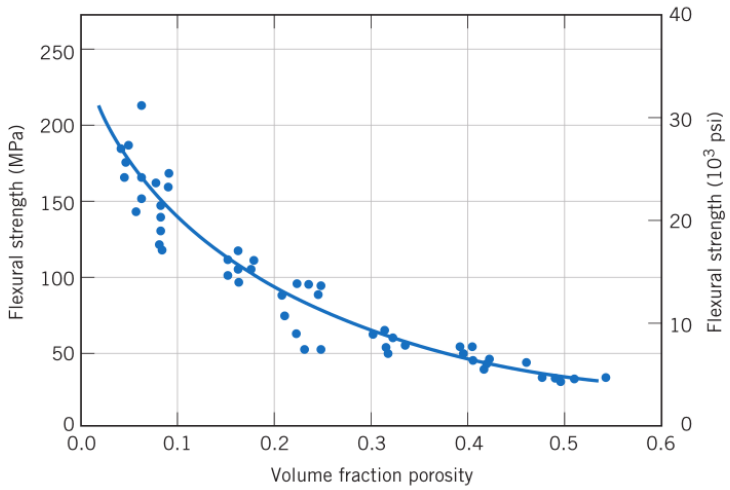
Adapted from *Callister 8e.*

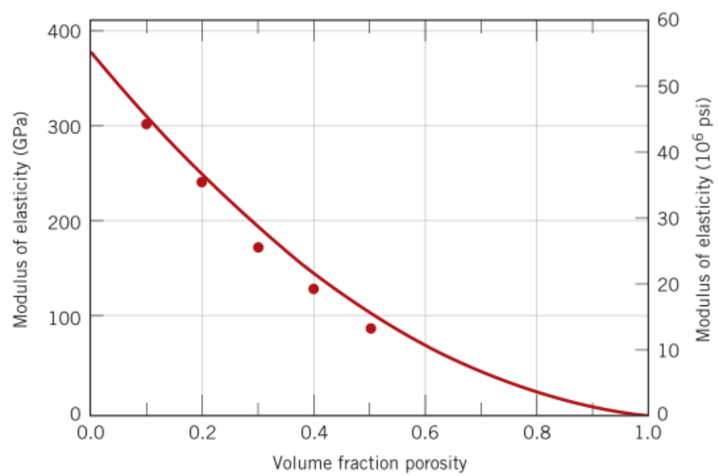
Material	Flexural Strength MPa	Flexural Strength ksi
Silicon nitride (Si_3N_4)	250–1000	35–145
Zirconia[a] (ZrO_2)	800–1500	115–215
Silicon carbide (SiC)	100–820	15–120
Aluminum oxide (Al_2O_3)	275–700	40–100
Glass-ceramic (Pyroceram)	247	36
Mullite ($3Al_2O_3$–$2SiO_2$)	185	27
Spinel ($MgAl_2O_4$)	110–245	16–35.5
Magnesium oxide (MgO)	105[b]	15[b]
Fused silica (SiO_2)	110	16
Soda-lime glass	69	10

Adapted from *Callister 8e.*

Porosity

- Ceramics often have significant porosity due to processing methods





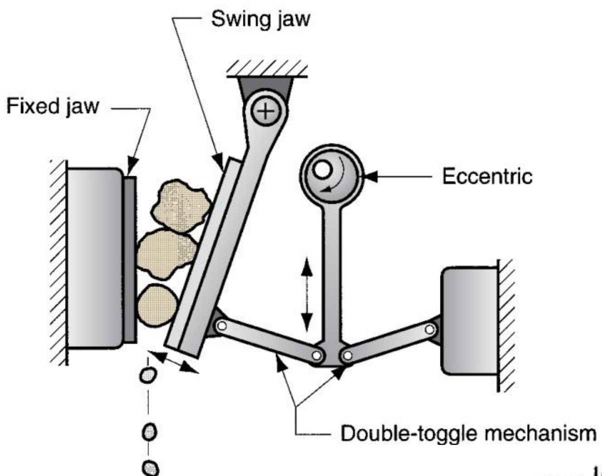
Adapted from *Callister 8e.*

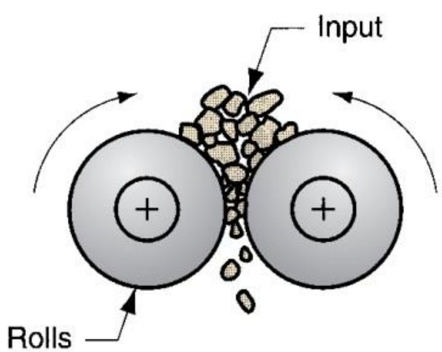
Mechanics In Design and Manufacturing

+ Ceramics Processing

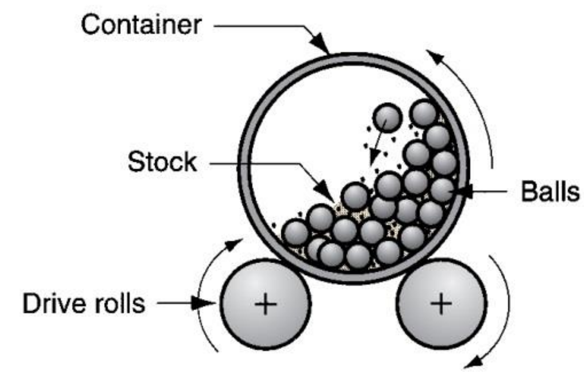
Powder Preparation

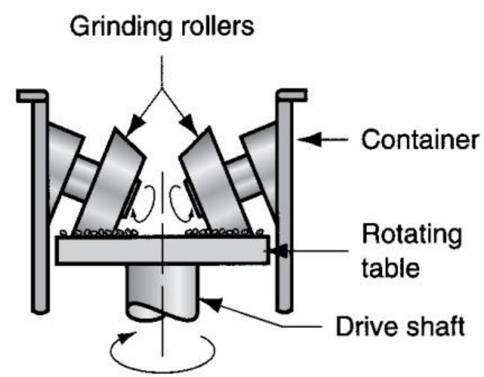
1) Crushing





2) Grinding/Milling



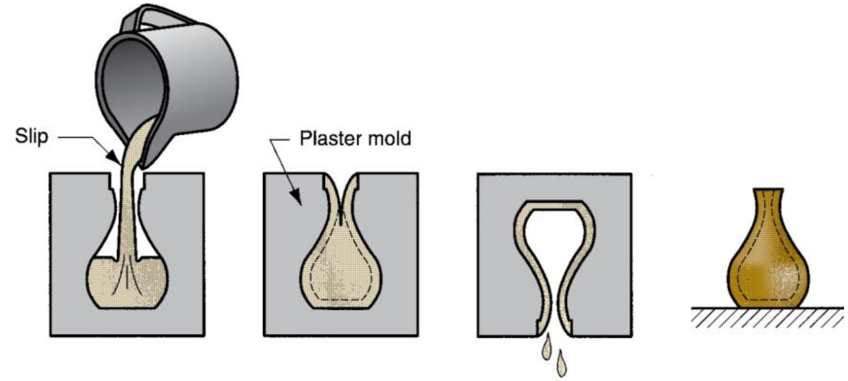


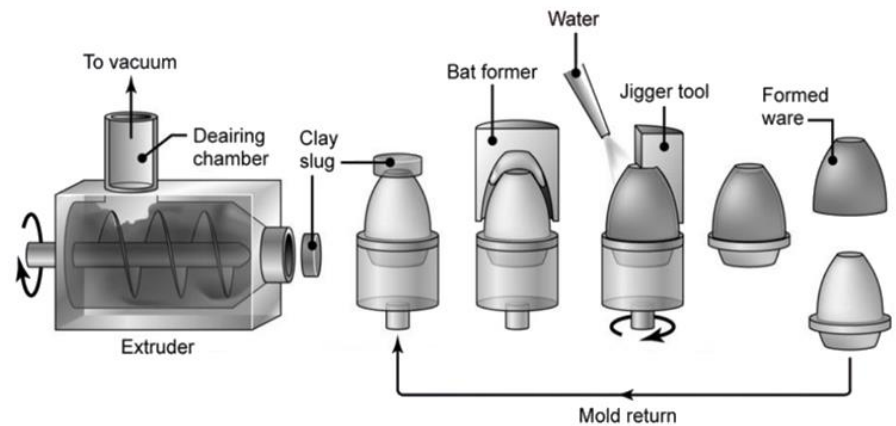
Video: Reciprocating Rock Crusher

Everything You Ever Wanted To Know About Ball Mills

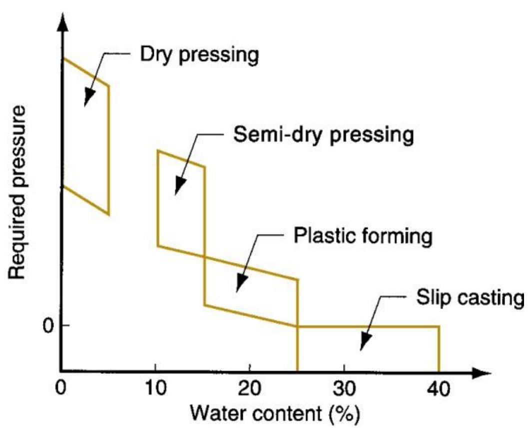
Shaping Processes

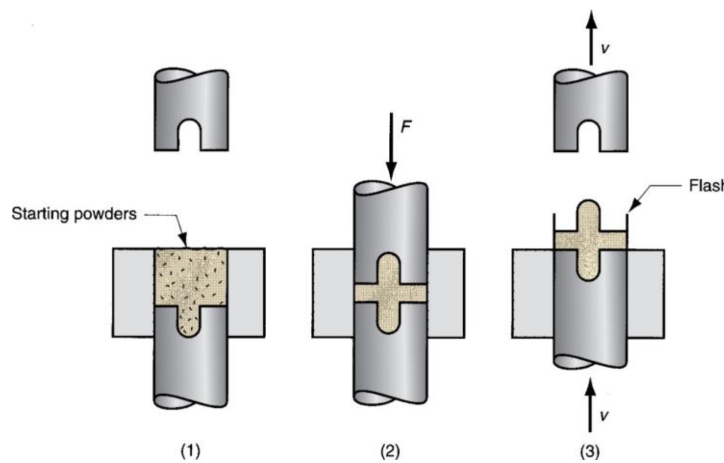
- Slip Casting
- Jiggering
- Pressing
- Extrusion





Kalpakjian and Schmid, 6th ed.



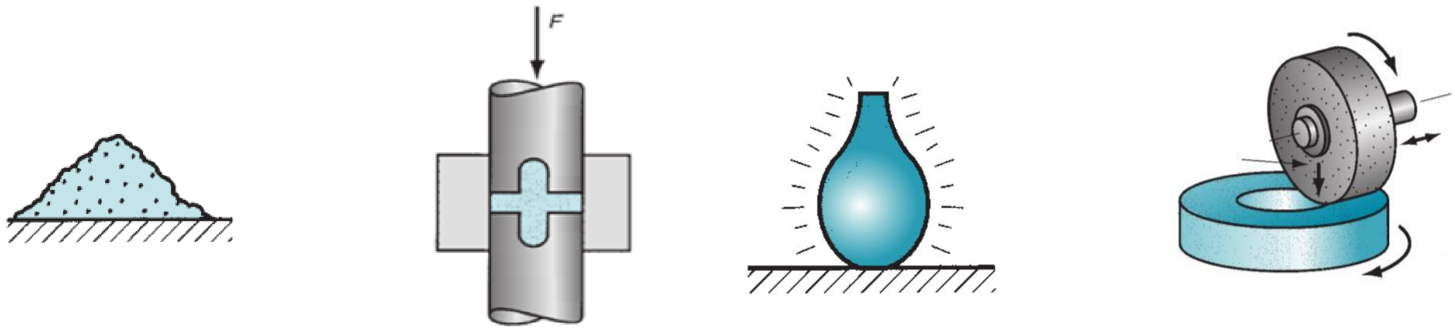


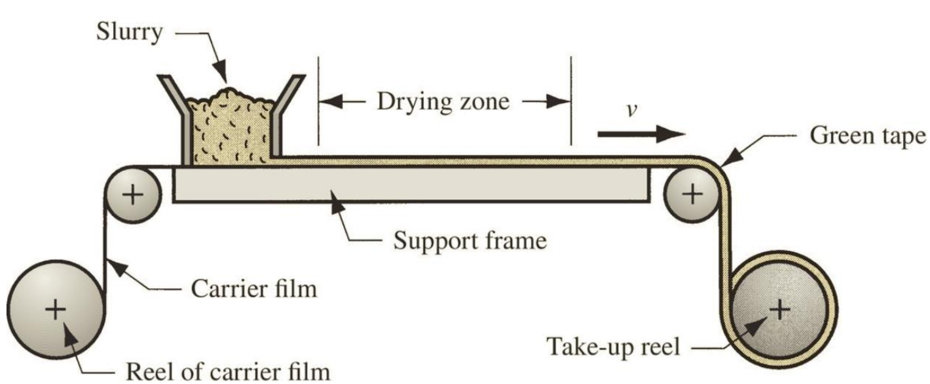
Drying, Firing, Glazing

Processing – Mass production mugs

https://www.youtube.com/watch?v=pYw5zUyiS7M

Processing New Ceramics





[Ceramic Machining]

[Beating silicon nitride bearing]