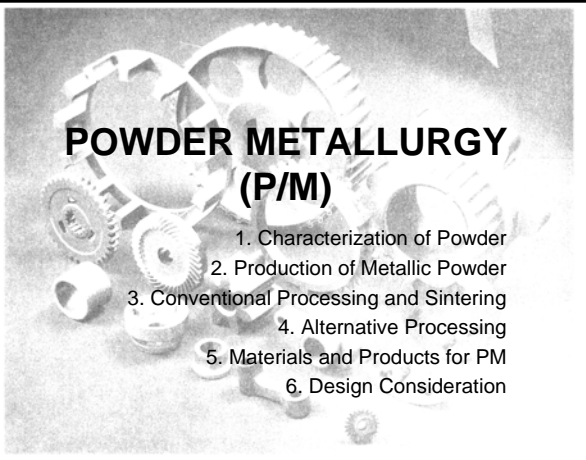


POWDER METALLURGY (P/M)

1. Characterization of Powder
2. Production of Metallic Powder
3. Conventional Processing and Sintering
4. Alternative Processing
5. Materials and Products for PM
6. Design Consideration



Introduction

- Feasible when
 1. the melting point of a metal is too high such as W, Ta, Mo
 2. the reaction occurs when melting such as Zr and for superhard tool materials
- Powder Metallurgy (PM) (around 1800s)
 - Pressing – Powders are compressed into the desired shape in a press-type machine using punch-and-die tooling designed specifically for the part.
 - Sintering - Heating at a temperature well below melting.
- Advantage
 - Near-net shape, No waste, controlled porosity, Dimension control better than casting
- Disadvantage
 - High cost of tooling and powder, Powder Harder to handle Geometric & Size limitation, Density variation

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1. Characterization of Powders

- P/M materials
 - Alloys of iron, steel, and aluminum, copper, nickel, and refractory metals such as molybdenum and tungsten and metallic carbides
- Geometric feature
 - Particle shape
 - Particle size
 - Particle distribution
 - They affects surface area, packing density, porosity, interparticle friction (Flow Characteristics), Green Strength
- Other Factors
 - (Chemistry and Surface Film)

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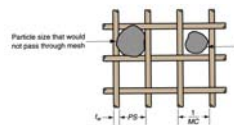
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Particle Shapes and sizes

- Particle Shape



- Particle Size (PS)



Mesh count refers to the number of openings per linear inch of screen. Thus, higher mesh count means smaller particle size

$$PS = \frac{1}{MC} - t_w$$

where PS = particle size
 MC = mesh count
 t_w = wire thickness

- Surface Area (SA) For spherical powder, $A = \pi D^2$; $V = \frac{\pi D^3}{6}$; $\frac{A}{V} = \frac{6}{D}$

How do SA and PS affect the final product?

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2. Production of Metallic Powders

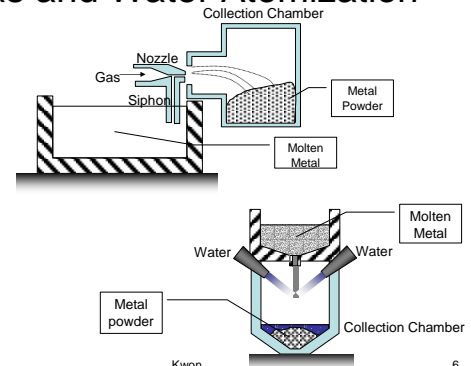
- Atomization
 - The molten metal is injected in a stream of Gas, Water or Centrifugal forces (e.g. rotating disk)
- Chemical Reduction – Liberation of metals from oxides. (Iron, Tungsten and Copper)
- Precipitation of metallic elements from the salts dissolved in water
- Electrolytic: Anode made of desired metal is dissolved into the solution. Cathode collects the deposit. (Beryllium, Copper, Iron, Silver, Tantalum and Titanium)

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Gas and Water Atomization



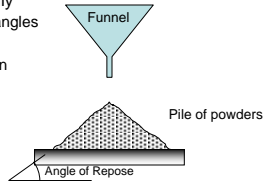
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Friction

- Intersurface Friction & Flow Characteristics
 - Friction between particles affects ability of a powder to flow readily and pack tightly
 - A common test of intersurface friction is the angle of repose, which is the angle formed by a pile of powders as they are poured from a narrow funnel
 - Smaller particle sizes generally
 - greater friction and steeper angles
 - Spherical shapes
 - the lowest intersurface friction
 - As shape deviates from spherical, friction between particles tends to increase



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Packing Factor (PF)

- True density
 - density of the true volume of the sintered material
- Bulk density
 - density of the powders in the loose state after pouring
 - bulk density ? true density
- Typical PF for loose powders: 0.5 and 0.7
 - powders of various sizes vs. uniform size
 - Compaction Pressure increases packing
- Porosity (P) - Ratio of the volume of the empty spaces in the powder to the bulk volume. (P+PF=1)

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3. Conventional Pressing & Sintering

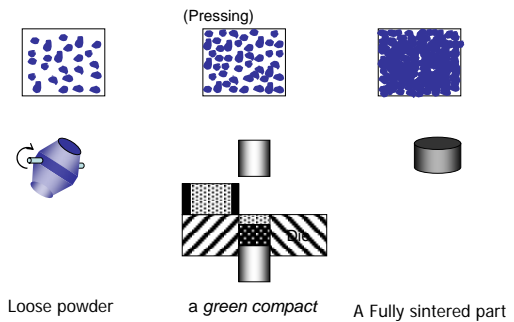
- Blending and Mixing
 - Blending – intermingling of powders
 - Mixing – combining powders of different chemistries
 - Additives – Lubricants, binders and deflocculants
- Pressing (Compaction) – green compact, low density and strength
- Sintering – increases strength and density
 - Reduction of surface energy
 - Necking, reduction of pore and grain growth
- Secondary Operation – Densification & sizing, Impregnation & Infiltration, Heat Treating & Finishing

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Blending, compacting & sintering



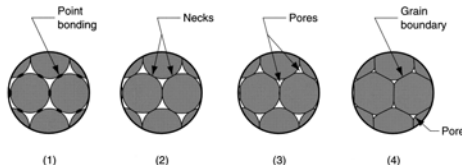
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Sintering on a microscopic scale

Sintering at between 70% and 90% of the metal's melting point (absolute scale)



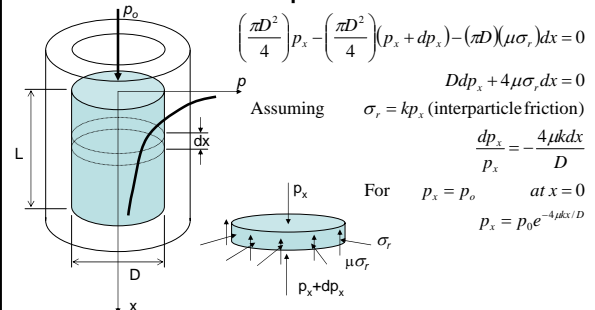
- (1) particle bonding is initiated at contact points;
- (2) contact points grow into "necks";
- (3) the pores between particles are reduced in size; and
- (4) grain boundaries develop between particles in place of the necked regions

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Pressure Distribution in Compaction



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Densification and Sizing

- Secondary operations to increase density, improve accuracy, or accomplish additional shaping
 - Repressing - pressing the sintered part in a closed die to increase density and improve properties
 - Sizing - pressing a sintered part to improve dimensional accuracy
 - Coining - pressworking operation on a sintered part to press details into its surface
 - Machining - creates geometric features that cannot be achieved by pressing, such as threads, side holes, and other details

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Impregnation & Infiltration

- Impregnation - when oil or other fluid is permeated into the pores of a sintered part.
 - oil-impregnated bearings, gears, and similar components
 - An alternative application is when parts are impregnated with polymer resins to create a pressure tight part
- Infiltration - An operation in which the pores of the PM part are filled with a molten metal with a lower melting point
 - capillary action draws the filler into the pores
 - Relatively nonporous, and more uniform density, as well as improved toughness and strength

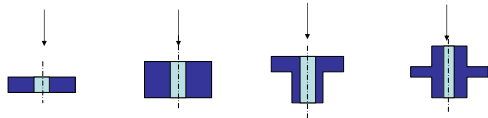
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PM Parts Classification System

The Metal Powder Industries Federation (MPIF) defines four classes of powder metallurgy part by level of difficulty



- (a) Class I - simple thin shapes, pressed from one direction;
 (b) Class II - simple but thicker shapes require pressing from two directions;
 (c) Class III - two levels of thickness, pressed from two directions; and
 (d) Class IV - multiple levels of thickness, pressed from two directions, with separate controls for each level

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4. Alternative Pressing

- Isostatic Pressing
 - Cold Isostatic Pressing (CIP)
 - Hot Isostatic Pressing (HIP)
- Powder Injection Molding (Metal & Ceramics)
 - Powder mixed with binder to form granular pellets
 - Pellets are heated to remove binder
 - Sintering and Secondary operation
- Powder Rolling, Powder Extrusion (powder in a container) and Powder Forging
- Hot pressing and Spark pressing (high electric current)
- Liquid-phase sintering

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Design Guidelines

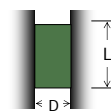
- Economics usually require large quantities to justify cost of equipment and special tooling
 - Minimum quantities of 10,000 units are suggested
- PM is unique in its capability to fabricate parts with a controlled level of porosity (up to 50%)
- PM can make parts out of materials that would be difficult if not impossible to produce by other means
- The part geometry must permit ejection from die after pressing.
- Wall thickness should be a minimum of 1.5 mm (0.060 in) between holes or a hole and outside wall
- Minimum recommended hole diameter is 1.5 mm (0.060 in)

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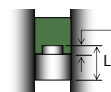
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Processing Capabilities



$L/D = 2$ (single action press)
 4 (double action press)



If $x > L/4$, high density gradient breaks the compact
 If $x < L/4$, density gradient is not high enough breaks the compact

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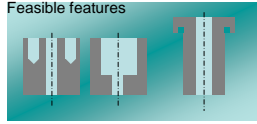
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Design features for PM

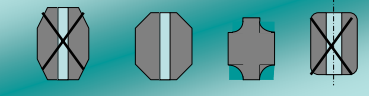
Features to avoid:



Feasible features



Punch end become fragile.



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PROCESSING OF CERAMICS AND CERMETS

1. Traditional Ceramic Processing
2. New Ceramic Processing
3. Cermet Processing
4. Product Design Consideration

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Introduction

- Traditional Ceramics – Minerals in nature and clay (mainly hydrous aluminum silicate).
- New Ceramics - synthetically produced raw materials.
- For traditional ceramics, powders are **mixed** with water, shaped, dried and fired.
- For new ceramics, powders are mixed with binders, **pressed** to form a green part and **sintered** into a final part.

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1. Traditional Ceramic Processing

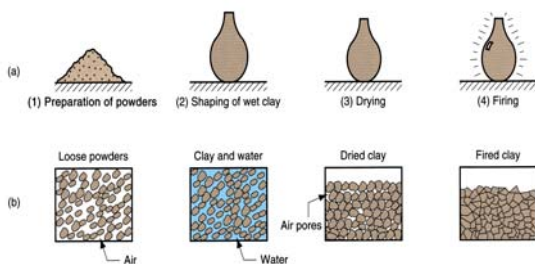
- Processing sequence
 - Preparing powders
 - Shaping of wet clay
 - Drying
 - Firing
- Preparation of Raw Materials
 - Comminution
 - Crushing
 - Grinding
- The more water in the mixture, the easier to form. But cracking during drying and sintering.

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Processing steps

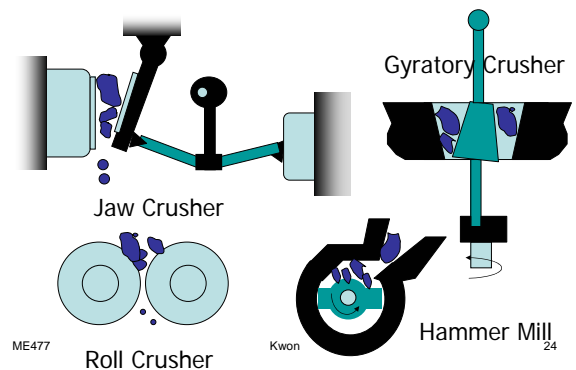


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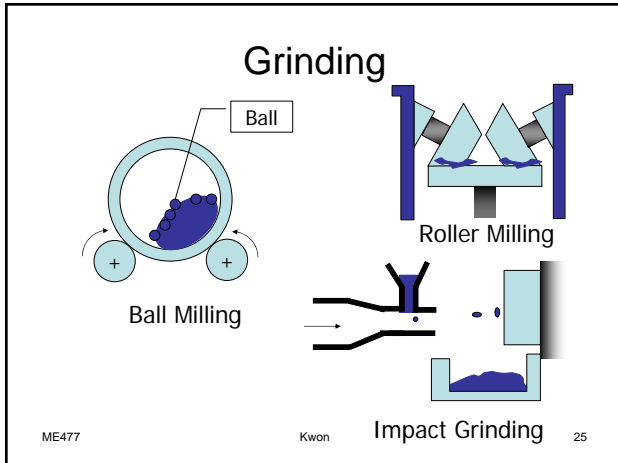
Crushing



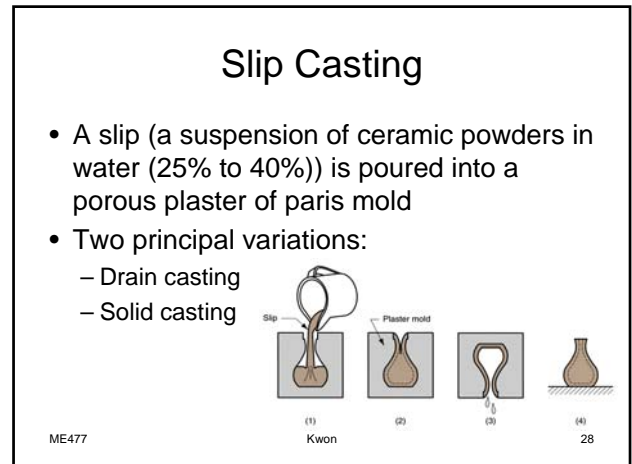
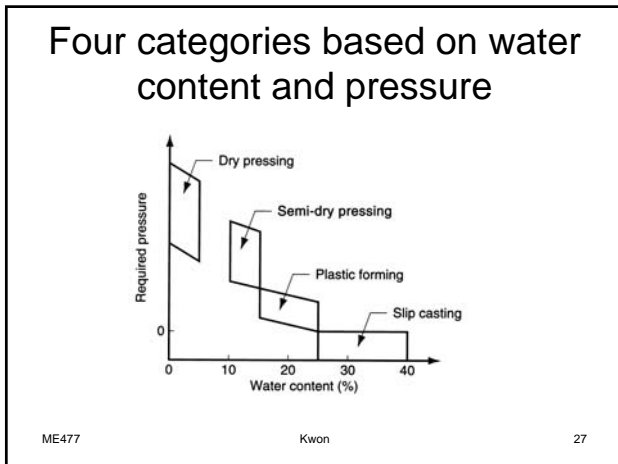
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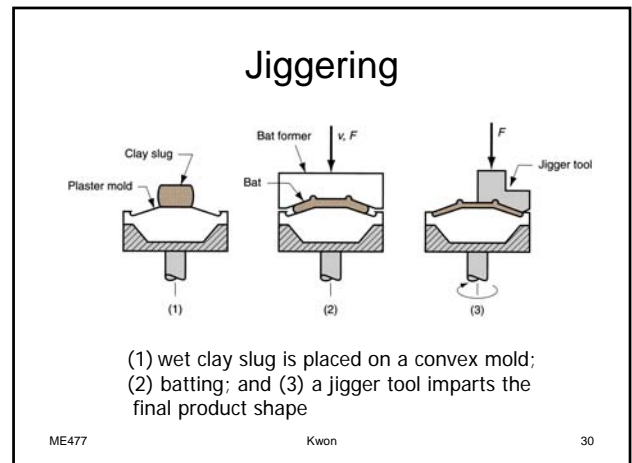
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- ### Shaping, Drying & Firing
- Depending on the consistency in mixture (required pressure to form)
 - Slip (A suspension of ceramic powders in water) casting (>25%)
 - Plastic forming (15 to 25%)
 - Semidry pressing (10 to 15%)
 - Dry pressing (<5%)
 - Drying
 - First stage - rapid drying with shrinkage
 - Second stage – slow drying with no shrinkage
 - Firing – green part in a furnace call kiln
 - Glazing – firing second time to coat
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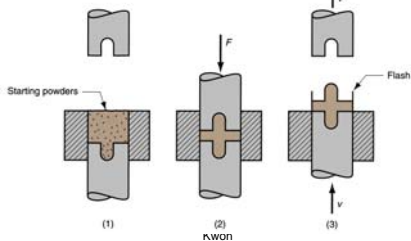


- ### Plastic Forming
- 15% to 25% water
 - Manual and mechanized methods
 - Hand modeling (manual method)
 - Hand molding
 - Hand throwing (e.g.: Potter's wheel)
 - Jigging (mechanized method)
 - Plastic pressing (mechanized method)
 - Extrusion (mechanized method)
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Semi-dry Pressing

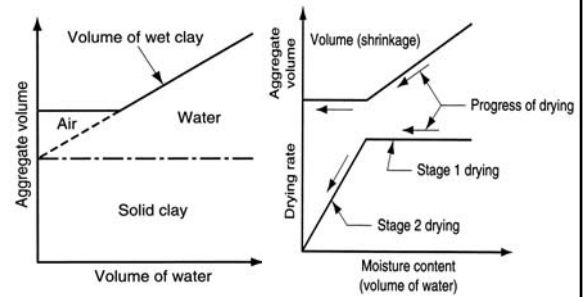
Uses high pressure to overcome the clay's low plasticity and force it into a die cavity



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Drying



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Firing and Glazing

- Firing - Heat treatment to sinter the ceramic material in a furnace called a kiln
 - Bonds are developed between the ceramic grains to densify the materials and to reduce porosity while additional shrinkage occurs.
 - A glassy phase forms among the crystals which acts as a binder
- Glazing - Application of a ceramic surface coating to make more impervious to water and enhance its appearance
 1. Fire the piece to harden the body of the piece
 2. Apply the glaze
 3. Fire the piece a second time to harden the glaze

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2. New Ceramic Processing

- Simpler chemistry such as oxides, carbides and nitrides
- Water does not necessarily enhance the flow properties.
- Higher strength, hardness
- Additives into starting powder
 - Plasticizer, binders, wetting, deflocculants and lubricants
- Processing steps
 - Preparation of powder
 - Shaping
 - Sintering
 - Finishing

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Preparation of powder

- Two Methods
 - Freeze drying – Salt is dissolved into water, which freezes into droplets. Then water is removed, which decomposes during heating.
 - Precipitation from solution – dissolved and filtered (Bayer process for Alumina)
- Greater control of the starting powders is required
 - The starting powders must be smaller and more uniform in size and composition, since the strength of the resulting ceramic product is inversely related to grain size.

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Shaping

- From Traditional Ceramic Processing
 - Slip casting, extrusion and dry pressing
- New Processes
 - Hot Pressing
 - Sintering is accomplished simultaneously with pressing.
 - Higher densities and finer grain size are obtained while sacrificing the die life.
 - Isostatic Pressing
 - Avoids the problem of nonuniform density
 - Doctor-blade Process
 - Powder Injection Molding
 - Mixed with a thermoplastic polymer, then heated and injected into a mold cavity

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Sintering and Finishing

- Sintering at 80-90% of melting temperature
 1. Bond individual grains into a solid mass
 2. Increase density
 3. Reduce or eliminate porosity
- Finishing
 1. Increase dimensional accuracy
 2. Improve surface finish
 3. Make minor changes in part geometry
- Finishing usually involves abrasive processes using Diamond abrasive
- Compared to the processing of the traditional ceramics, the details are often quite different.

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Secondary Operation

- Secondary operations are needed to achieve adequate dimensional control.
- Grinding
 - A diamond or other very hard abrasive wheel is the most common secondary operation
- Others
 - EDM
 - Ultrasonic machining

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4. Design Consideration

- Ceramics - Good for compressive loading not tensile loading
- Brittle and no ductility
- Simple in shape
- Edge and corner: radii and chamfers except cutting tool (sharp edges)
- Shrinkage
- No Screw

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