Metal Powder Industries Federation

Allowing Fit, Form, & Function to Drive Design

Introduction

PM provides the opportunity for cost effective production of complex net shape components.

Considerations When Designing for PM Processing

Production Quantity

Required Shape vs. Required Modifications

PM Processing

Mechanical and Physical Property Requirements

Cost vs. Existing or Competing Processes

Planetary Carrier (MPIF)

PM Processes – MIM, PF, HIP

Powder Forging

HIP/CIP

MIM

Photos Courtesy MPIF

PM Processes – "Press & Sinter"

Press and Sinter

↓

Most Common and Economical

↓

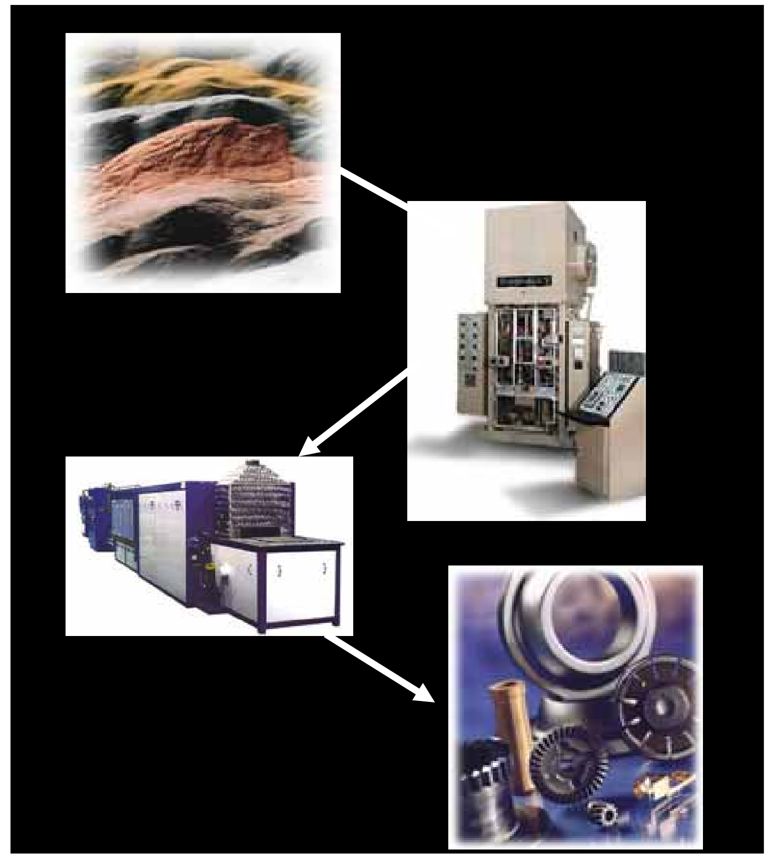
Dry Blend Powder + Compaction + Sintering

↓

Gears, Sprockets, Bushing, Cams, Etc

↓

Automobiles, Appliances, Power Tools and Equipment, etc.



Photos Courtesy MPIF

Designing for PM Processing

Shape & Tolerances

Application

Surface Area

Compaction Requirements

Finishing Operations

Material Requirements

Output Shaft for Ford Truck Transmission (MPIF)

Designing for “Press & Sinter” PM

- Considerations
- Tolerances
- Design Features

Density

- Mechanical Properties Improve as the Amount of Porosity is Reduced
- Tensile Strength is almost a Linear Function of Density
- Ductility, Toughness, and Fatigue Strength are Even More Dependent on Density
- They Increase Significantly at Low Levels of Porosity

Mechanical Properties

- **Ferrous PM Materials can match the Strength of Cast and Wrought Products**
- **However, PM Materials Generally cannot match the Combination of Strength and Ductility, or Impact Energy of the Wrought or Cast Products**
- **Remember, However, that the Properties of Wrought Products are not Isotropic. The Properties in the Longitudinal Direction (Relative to the Rolling Direction) are Markedly Better than they are in the Transverse or Short Transverse Direction**

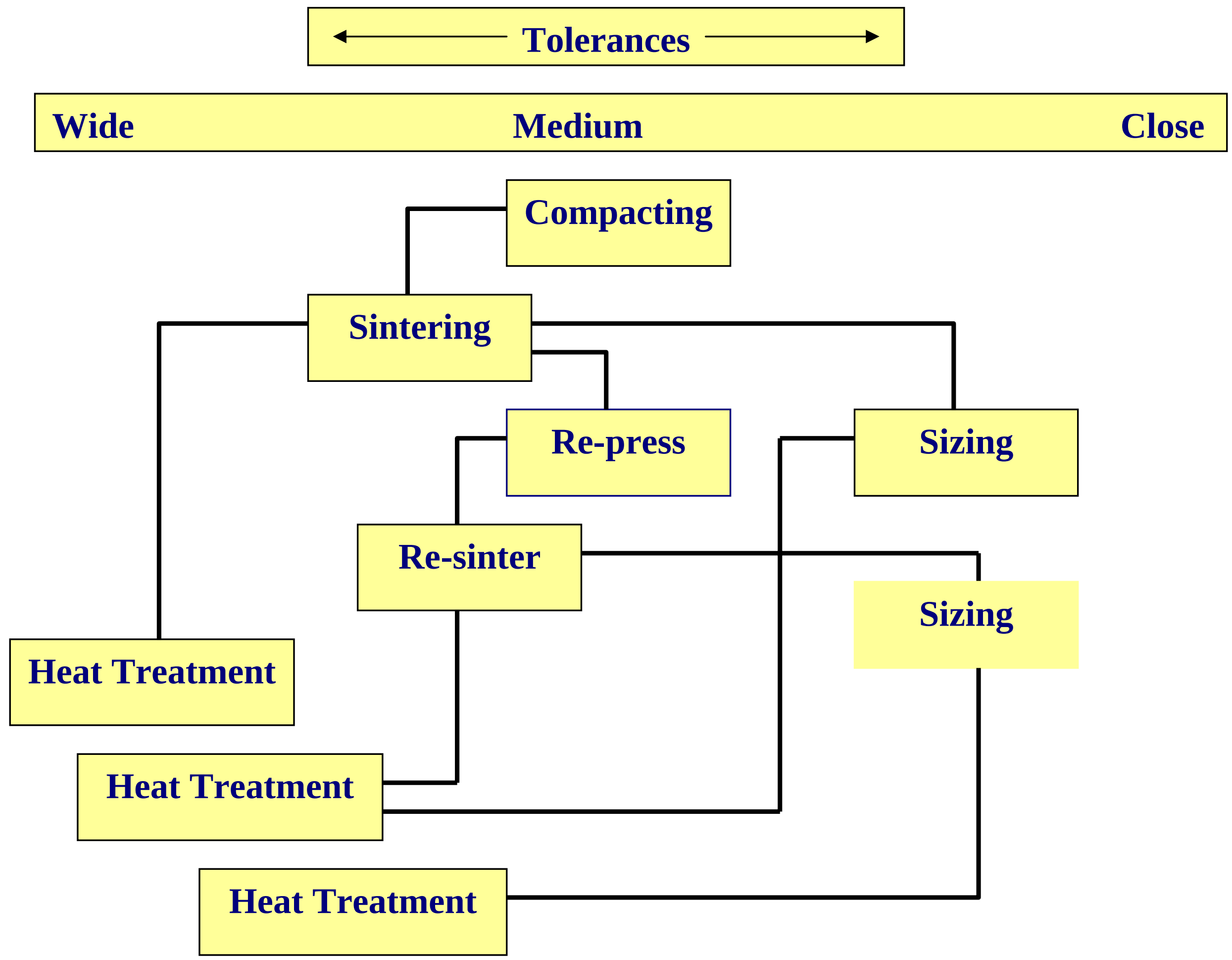
Dimensional Tolerances

Factors that can Affect Dimensional Change:

1. Perpendicular/Parallel to Pressing Direction
2. Part Size
3. Part Complexity
4. Material Formulation
5. Tool Wear
6. Finishing Operations – Coining, Heat Treatment, etc.

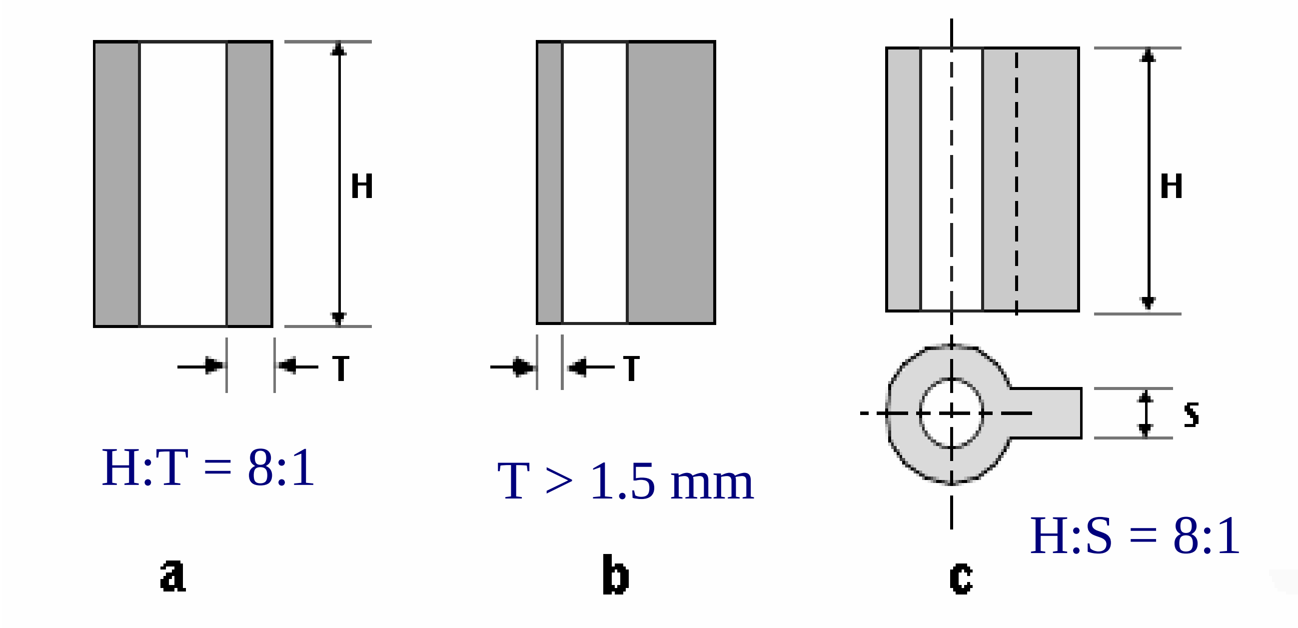
Gear Ass'y (MPIF)

Dimensional Tolerances

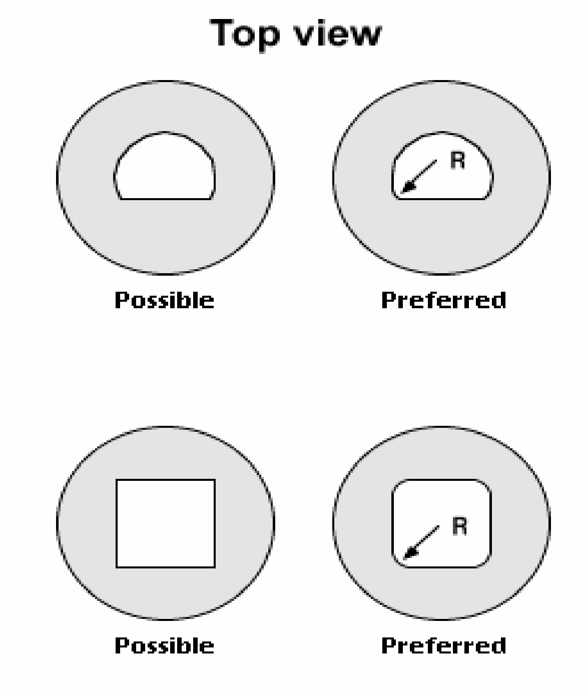


Holes and Wall Thicknesses

- Wall Thickness
  - Narrow walls are to be avoided



Design features to be preferred and to be avoided

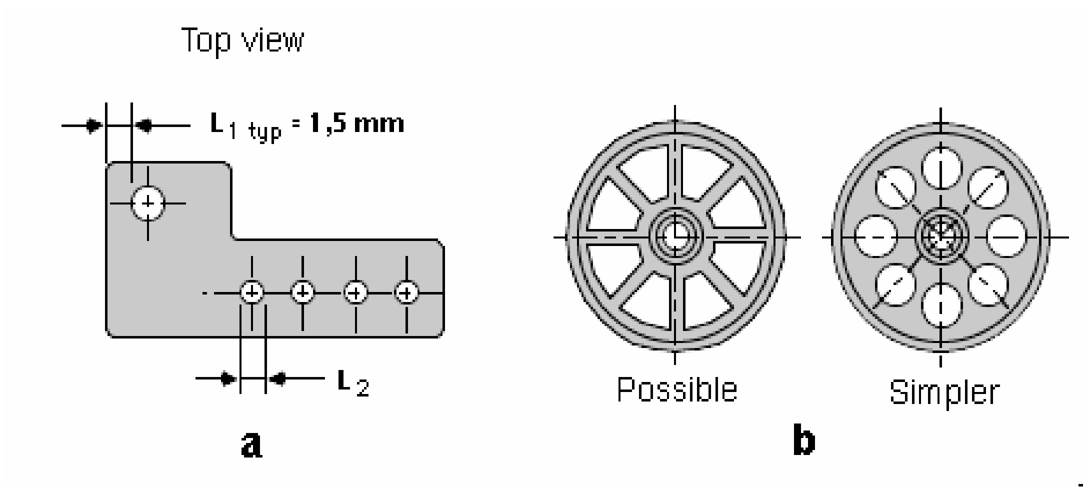


- Corners and edges facing the core rod and punches
  - Include radius to avoid cracking of parts and tools.

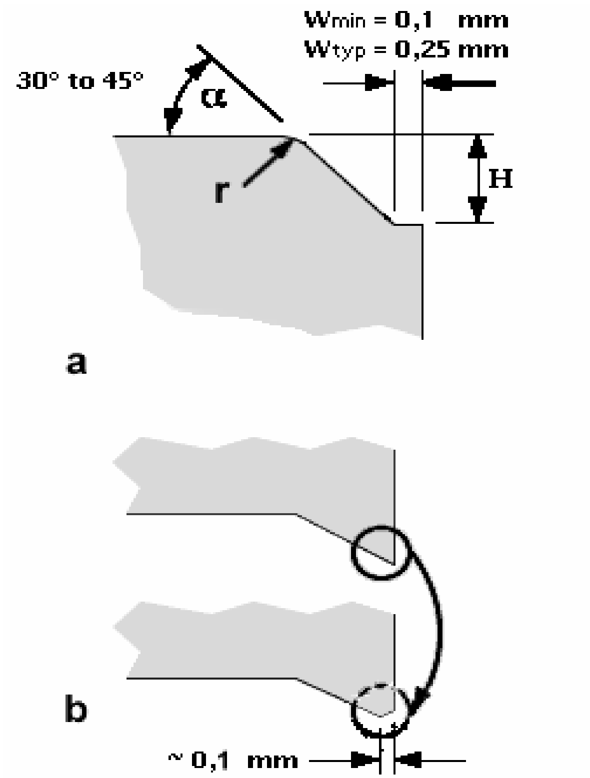
Holes and Wall Thicknesses

- Holes
  - Easy to make using core rods

    b) Round holes are more economical to make as tool maunfacturing is easier.

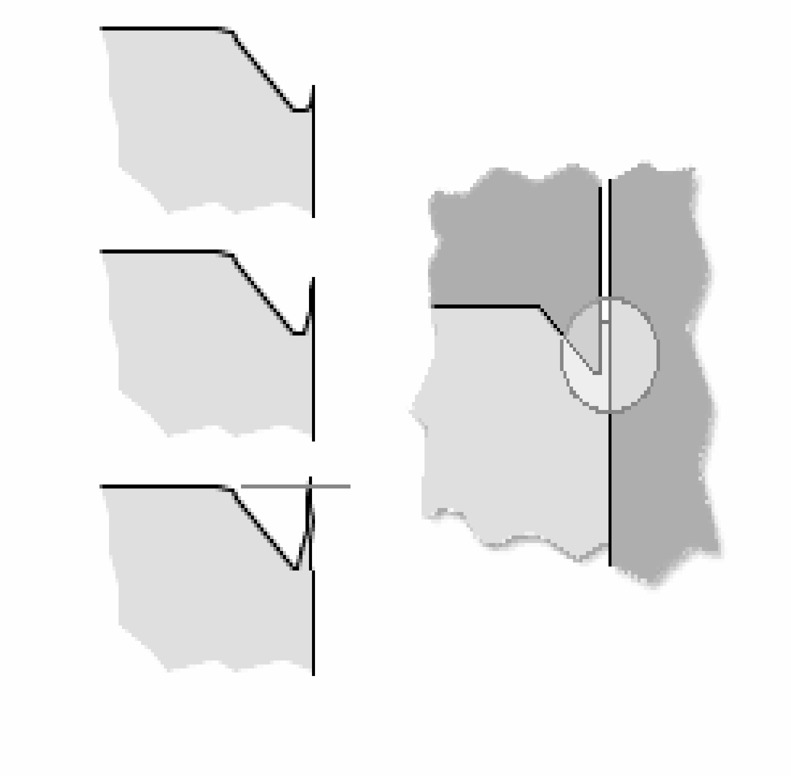


Design Features



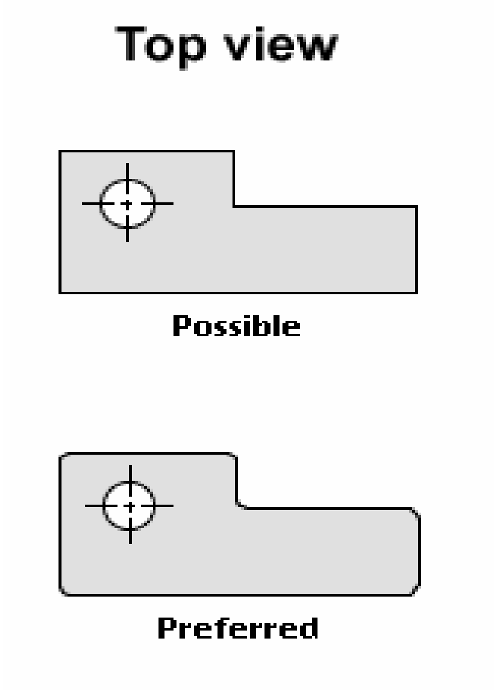
- Chamfers
  - Observe
    - Wmin = 0.1mm
    - H = 20% total height max
    - α = 45° max
    - Largest r possible

Design Features – Why Chamfer?



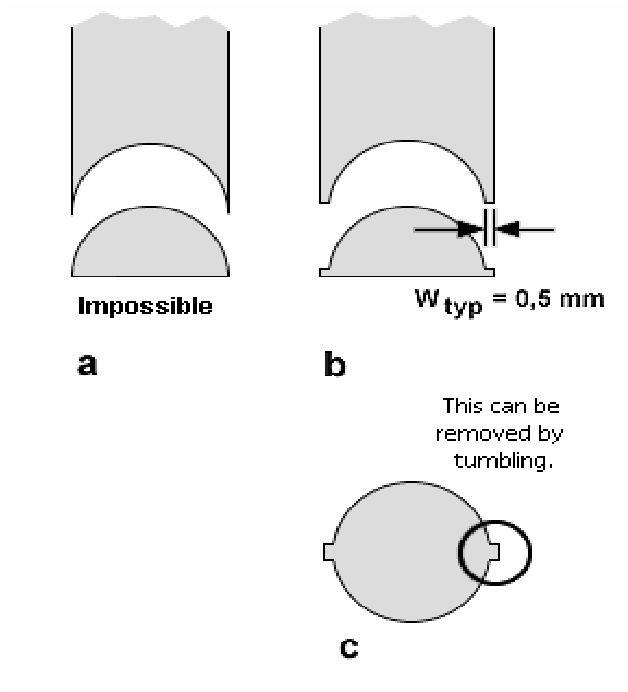
- Chamfers & Burrs
  - Burrs occur due to clearance between sliding tool members, but can be minimized by correct chamfer design.
  - However, due to tool wear, burr size will increase, so refacing of punches is required.

Design Features



- Corners and edges facing the die
  - Sharp corners are to be avoided, as there is risk of cracking the tools.

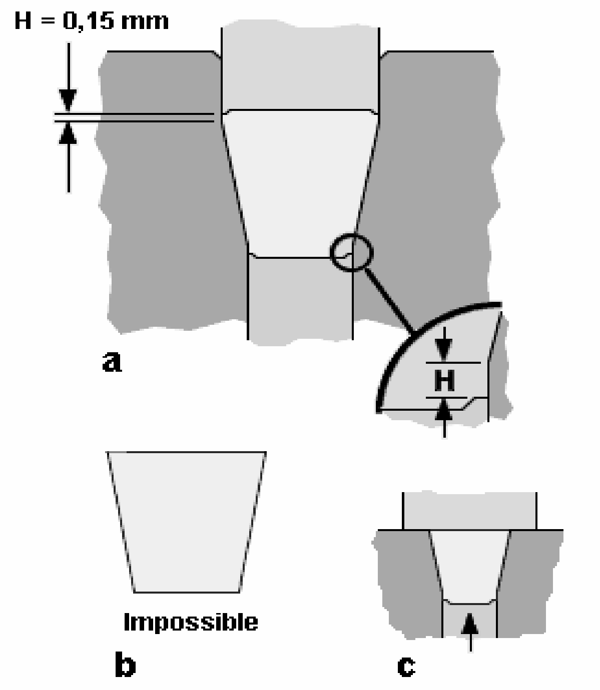
Design Features



- Spherical ends
  - True hemisphere can't be produced from pressing.
  - A flat is required

    W = 0.5 mm typical

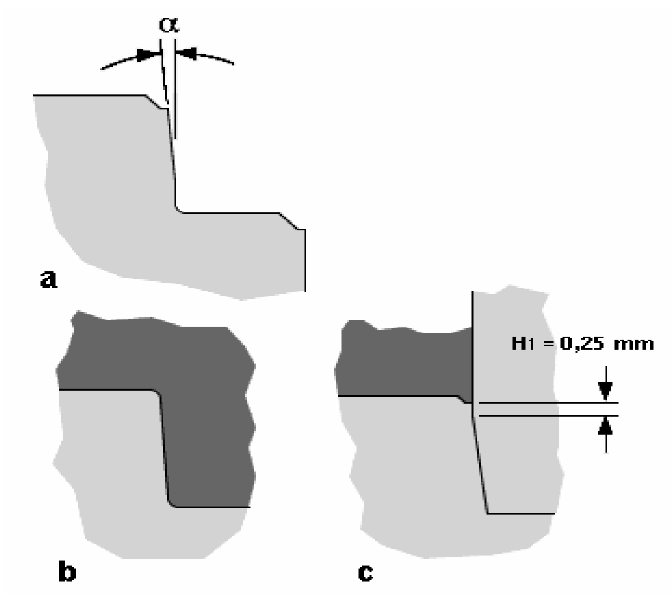
Design Features



- Tapered sides formed by the die
  - True conical parts can't be made (b)
  - Flat zones must be incorporated to avoid driving the punches into the die (a)

    H_{min} = 0.15mm

Design Features



- Tapered sides formed by upper punches

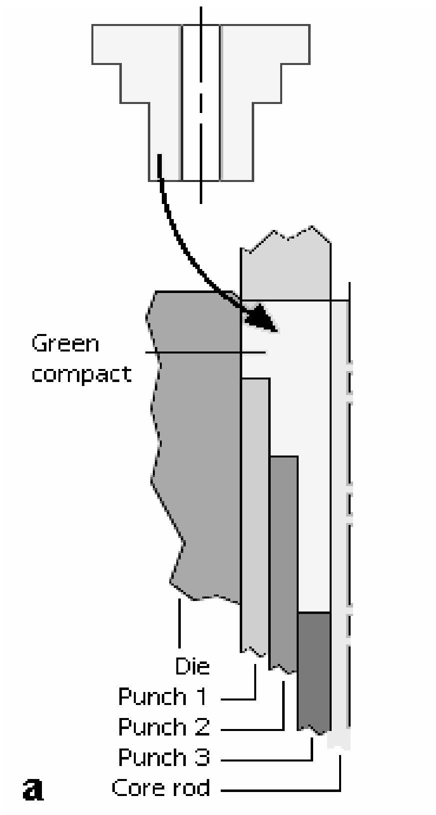
  (a) This form is challenging

  (b) Taper formed by upper punch: α_{min} = 2°, radii recommended

  (c) If the taper is to be formed using 2 punches then a chamfer and a straight portion should be incorporated

  $H1_{min}$ = 0.25mm

Design of multiple level parts

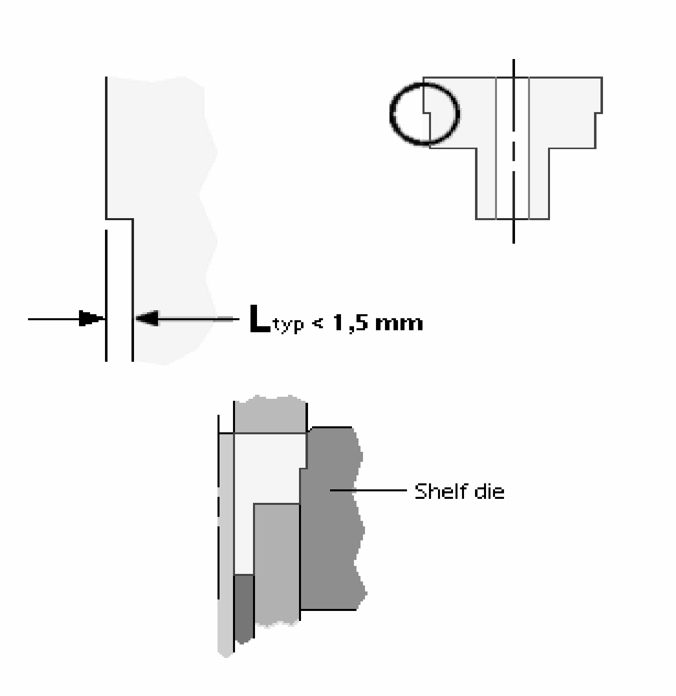


- Using multiple punches
  - Where the width of the steps allow it multiple punches should be used.

    W_{min} = 1.5mm
  - Tooling must be designed to avoid excessive buckling under load

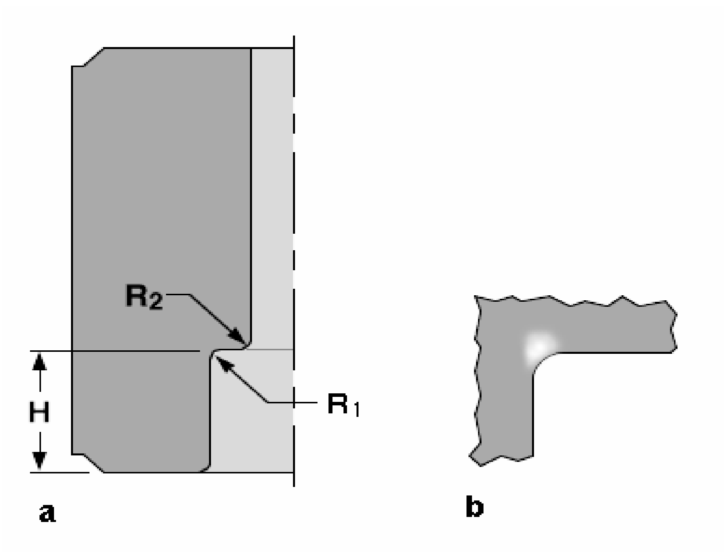
Transmission Outer Race (MPIF)

Design of multiple level parts



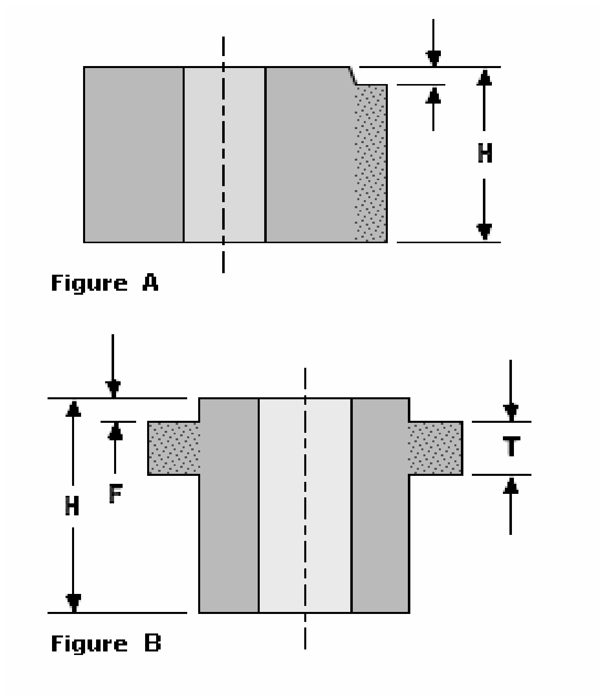
- Shelf Dies
  - Used when the step width does not allow multiple punches, i.e. L <1.5mm
  - May lead to density distribution differences
  - Taper and radius are required to avoid cracks and ease ejection.

Design of multiple level parts



- Stepped core rod
  - Larger radius increases life of core rod, but also increases problems of low density in radius. A recommended radius is 0.5 mm.

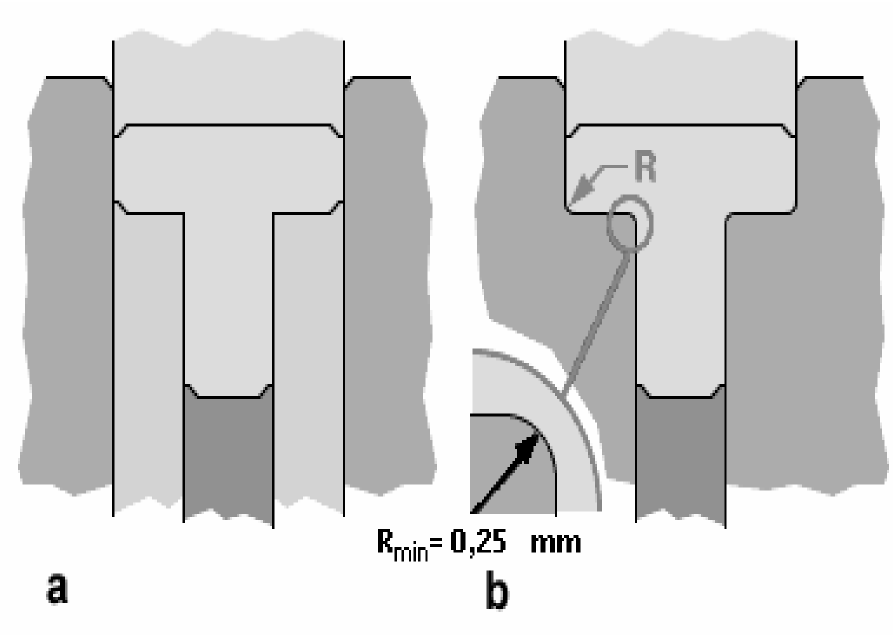
Design of multiple level parts



- Step in the punch face
  - a) A step can be obtained directly by a single punch providing the height does not exceed 20% of the parts total height.
  - b) When using a single upper punch to press a flanged part, the body height, F, must not exceed the thickness, T.

    Could be produced using two punches with powder transfer.

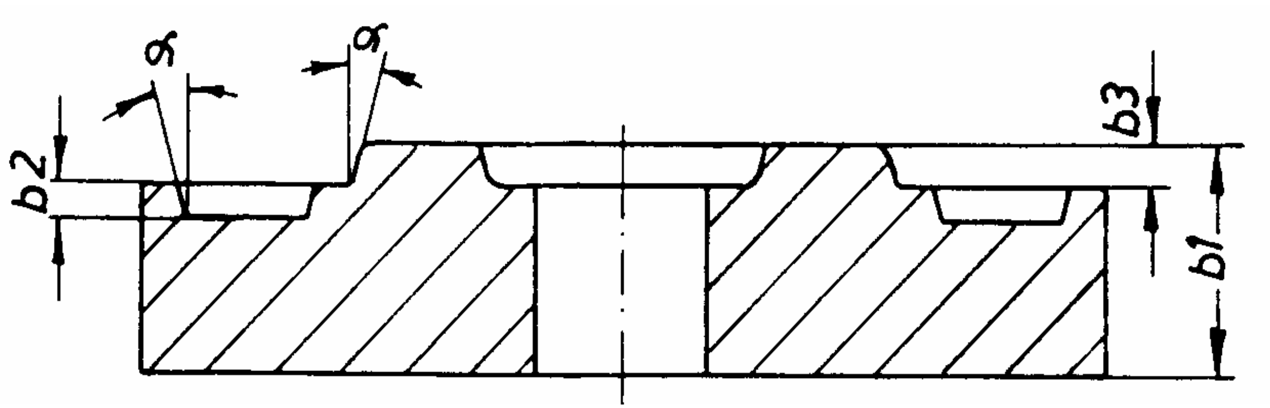
Design of multiple level parts



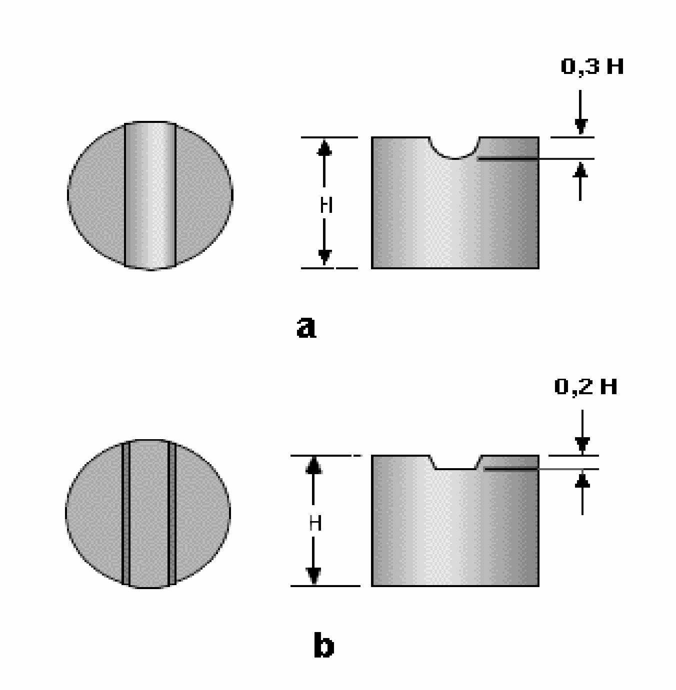
- Fillets
  - a) When the part is formed using 2 lower punches, a fillet radius is not required
  - b) When using a shelf die a 0.25 mm radius should be used to avoid cracking during ejection.

Design of multiple level parts

- Profiled faces
  - Can be produced if b2 <0.2b1, and b3 <0.1b1
  - αmin = 5°



Design of multiple level parts



- Slot made by a punch

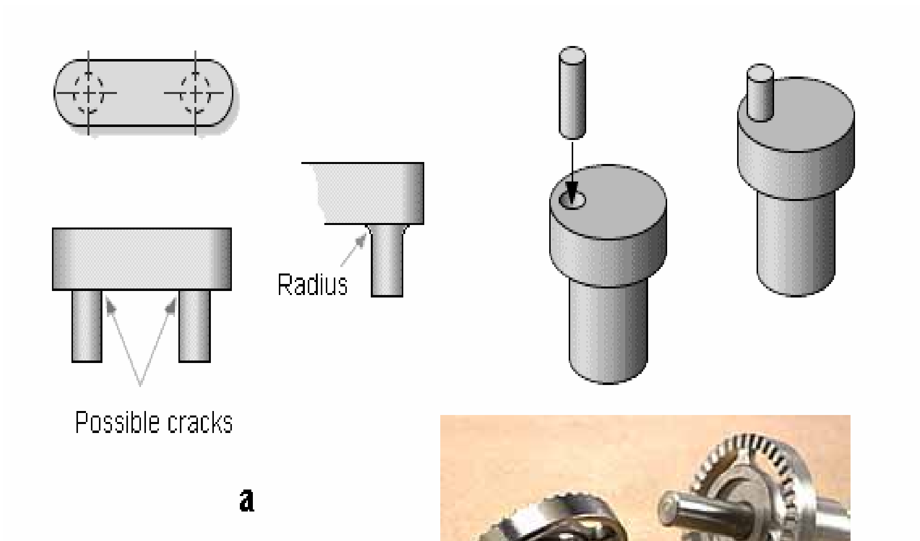
a) Semi circular,

max depth of slot is 30% of total height.

b) Angled,

max depth of slot is 20% of total height

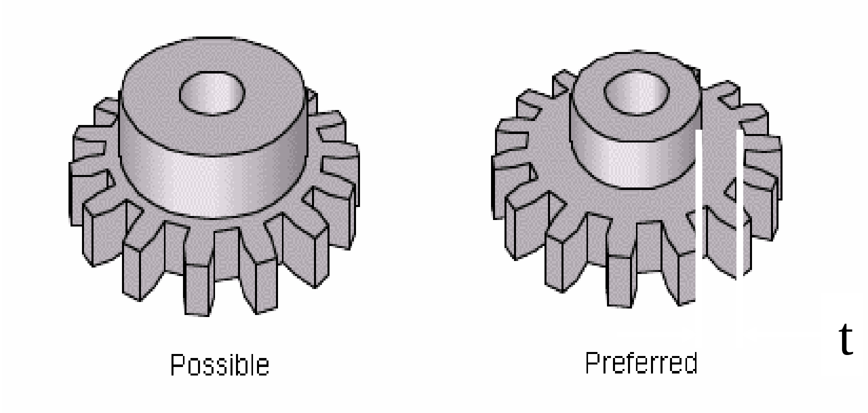
Design of multiple level parts



- Flanges and Studs
  - Use radii to avoid potential crack
  - Alternatively, can be made of 2 parts assembled before or after sintering

Gear Assembly (MPIF)

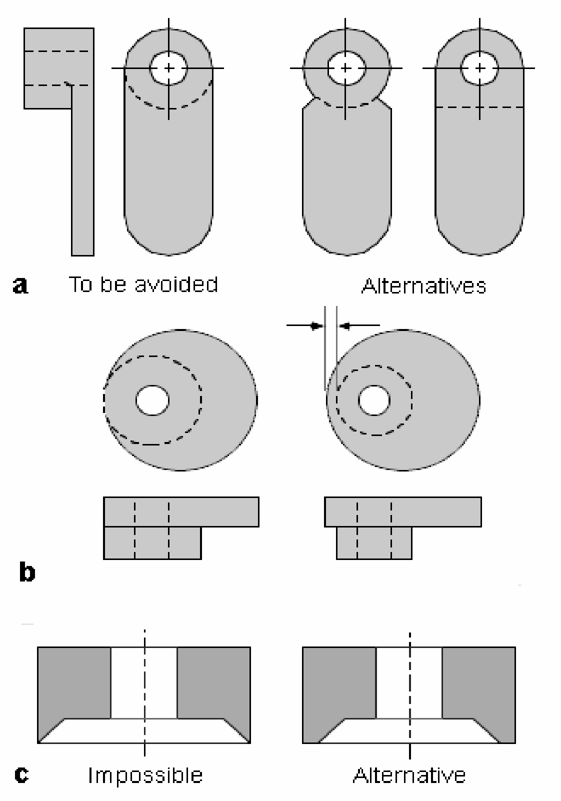
Design of multiple level parts



- Gear Hubs
  - t >1.5mm where possible

Hub Assembly (MPIF)

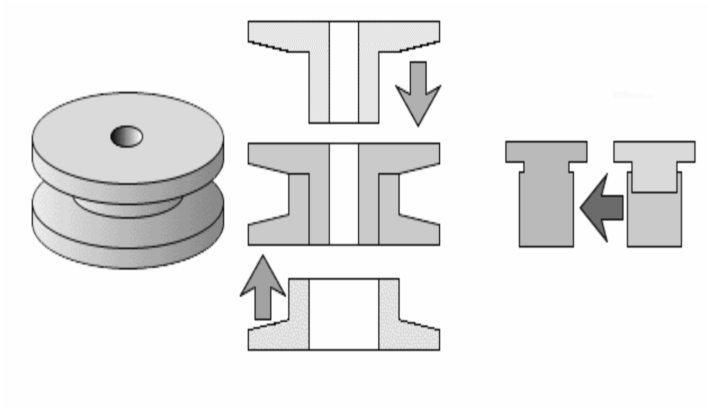
Holes and Wall Thicknesses



- Feathered edges
  - Tooling would be extremely fragile.

Transmission Gears (MPIF)

Assemblies



Brazed Carrier (MPIF)

- Complex Assemblies can be made before or after sintering
  - Brazing
  - Welding
  - Shrink Fit

Planetary Gear Carrier

Material Requirements

- The material system for this complex three piece part requires the balance of strength and dimensional control to facilitate brazing all three pieces together
  - **FC-0208: Fe-2.0%Cu + 0.8%Carbon + 0.35%MnS (for machinability)**
  - **Parts joined using a sinter-brazing compound**
  - **Density: 6.8 g/cm^3**
  - **Apparent Hardness: 85 HRB min**
  - **Tensile Strength 448 MPa (65,000 psi)**

Planetary Gear Carrier

PM Process Considerations

- Each of the three components are pressed with great control to ensure the proper dimensional response, the punch movements are precisely controlled to ensure the proper density distribution

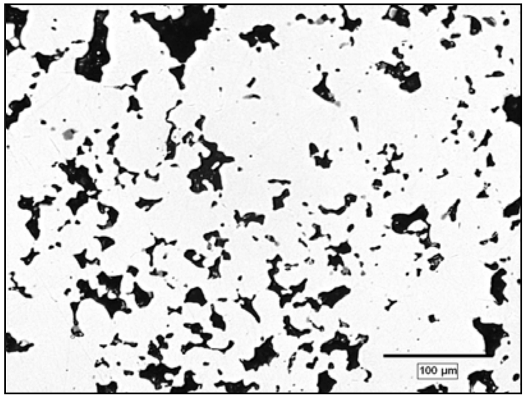
- Secondary operations on this complex part include sizing, turning, broaching of the internal spline, sinter-brazing, drilling of cross holes, deburring, balance audit, and burnishing of the hub

Planetary Gear Carrier

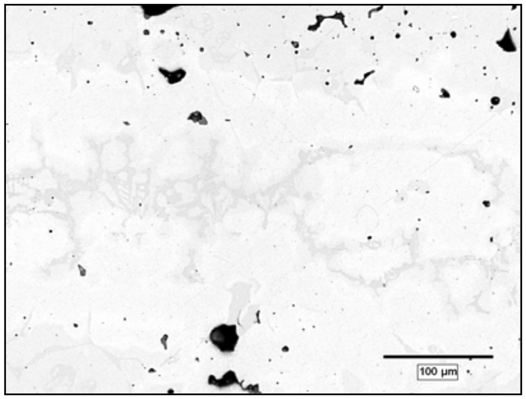
PM Process Considerations

- All three parts are produced from the same alloy with the same carbon content to facilitate brazing
- The sinter-brazing process is used where a special sinter-brazing compound + flux is placed on the braze joints during sintering allow for complete bonding of the two parts, the resulting seem is sintered join that is stronger than the matrix

Part core microstructure



Microstructure of the Braze Joint



Planetary Gear Carrier

Benefits of using PM

- The assembly is used in heavy duty transmissions and meets all design stiffness and pin deflection requirements
- PM used over competitive forged and stamped steel components joined by welding
- Carrier assembly has been validated to 200,000 miles

Forward-Reverse Actuator Assembly

Material Requirements

- The diversity of material performance required the use of sinter-hardened materials
  - Sinter-Hardening PM Grade:
    - Fe-Ni-Mo-Cu-C
  - Density: 6.9 g/cm^3
  - Tensile Strength: 830 MPa (120,000 psi)
  - Yield Strength: 760 MPa (110,000 psi)
  - Fatigue Strength: 300 MPa (43,000 psi)
  - Apparent Hardness: 35 HRC min

Forward-Reverse Actuator Assembly

PM Process Considerations

- No machining of the PM parts within the assembly is needed
- Sinter-hardening is used to eliminate the need for secondary quench and tempering
- Secondary operations include zinc plating and vacuum oil impregnation for corrosion resistance

Forward-Reverse Actuator Assembly

Benefits of using PM

- The assembly provides forward-reverse gearing for a golf cart
- The completed assembly contains six PM components that require no additional machining
- The end customer estimated that the use of PM in this assembly provided a cost savings of 50% when compared to competing technologies

Helical Gear for Power Tool

Material Requirements

- Used in a precision miter saw
- This part required the ability to achieve high strength along with high density to meet the wear and durability requirements.
  - **Warm Compacted PM Hybrid Alloy: Fe-Mo+Ni+C**
  - **Teeth compacted to a 7.3 g/cm^3 min**
  - **Tensile Strength: 690 MPa (100,000 psi) min**

Helical Gear for Power Tool

PM Process Considerations

- This 22° helix angle, 28 pitch gear’s teeth are formed during the compaction
- Use of warm compaction, where the powder and the compaction tool are heated, achieves a high density, 7.2 g/cm^2, with 7.3 g/cm^3 in the gear teeth

Helical Gear for Power Tool

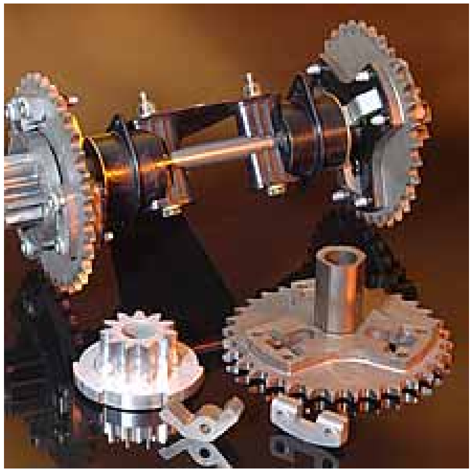
Benefits of using PM

- Using PM for this part eliminated the need to produce the same component by gear hobbing 4140 blanks
- The use of warm compaction provided enough density to meet the design requirements formerly achieved using 4140 steel

Assembly for Snow Blower

Material Requirements

- Free-Wheeling Steering System Axle Assembly for a snow blower, each part had unique property requirements requiring the use of different PM materials
  - **Pawl Latch Gear & Sprocket**
    - **FL-4405-100HT: Fe-0.85%Mo+0.5%C**
    - **Heat-Treatment: Quench and Temper**
    - **Density: 6.7 g/cm^3**
    - **Apparent Hardness: 19-35 HRC for the Pawl Latch Gear, 24 HRC min for the Sprocket**
    - **Tensile Strength: 480 MPa (70,000 psi) min**
  - **Clutch Pawl & Pawl Support**
    - **FLC-4608-70 HT: Fe-1.8%Ni+0.5%Mo+2.0%Cu+0.8%C**
    - **Heat Treatment: Sinter-hardening**
    - **Density: 6.8 g/cm^3**
    - **Apparent Hardness: 60-70 HRA**
    - **Tensile Strength: 480 MPa (70,000 psi) min**



Assembly for Snow Blower *PM Process Considerations*

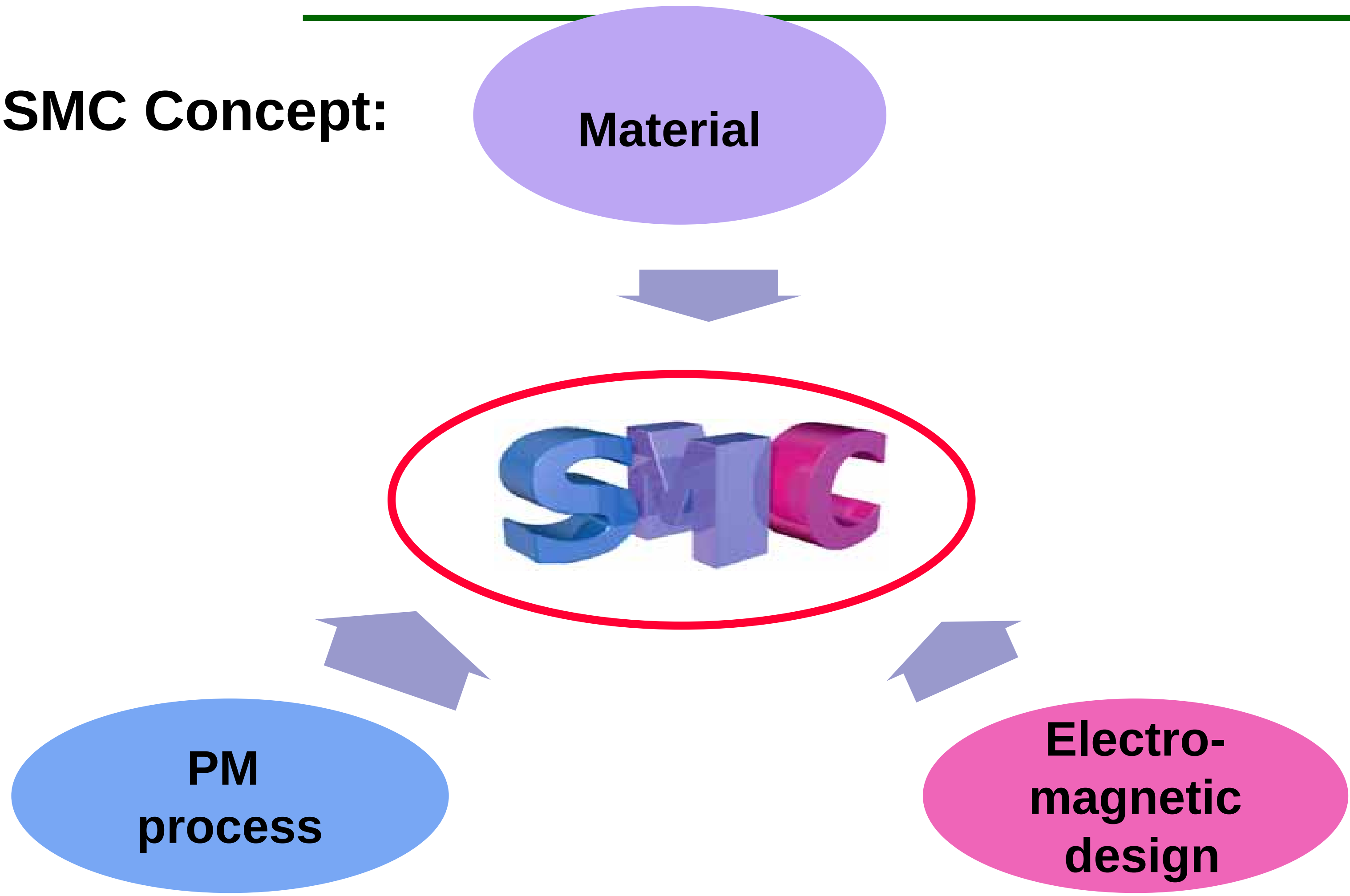
- All PM parts used in this assembly are net shape, no additional machining is required
- The only secondary operations used on the PM parts are deburring and honing of the sprocket bore
- The clutch pawl is sinter-hardened so that the porosity can later be filled with a lubricant to provide lubricity with the mating parts
- PM parts include single level parts to multi-level parts with complex geometry and use core rods

Assembly for Snow Blower

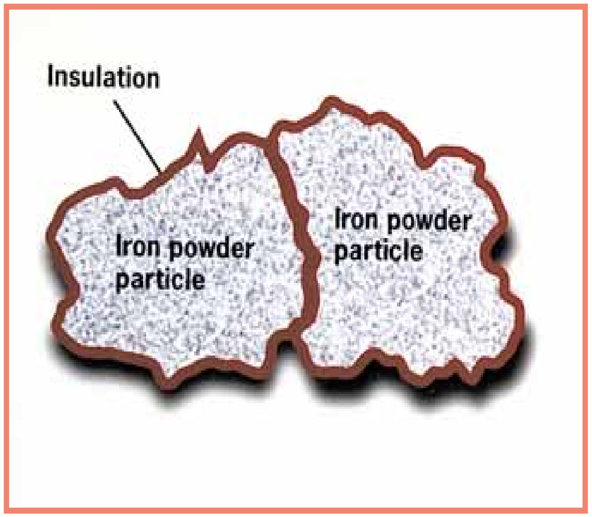
Benefits of using PM

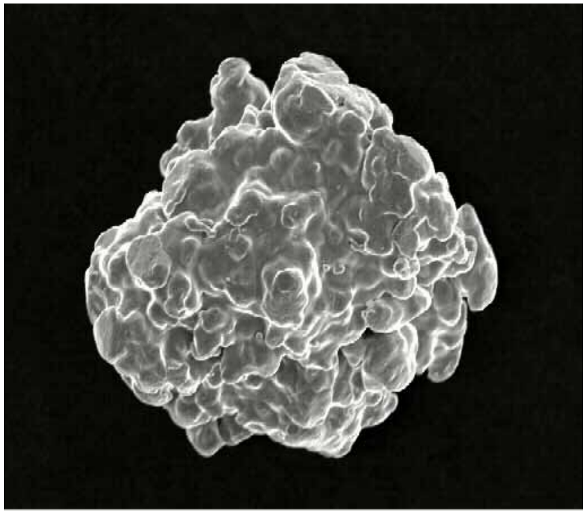
- The completed assembly contains 16 PM components
- PM was used in place of machined castings and wrought materials
- The completed assembly passes all life and shock testing requirements
- Subzero operation and corrosion testing was completed without any failures

SMC Concept:



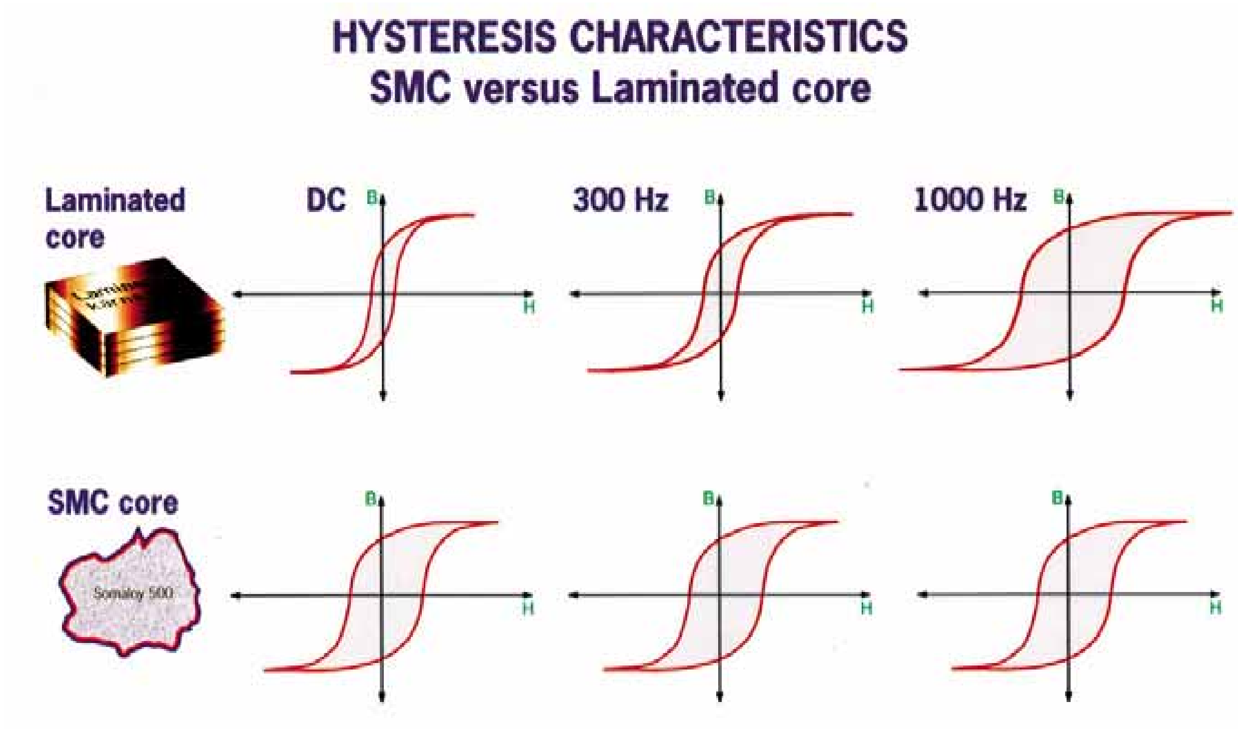
SMC Fundamentals:





Electrically Insulated Fe-powder Particles

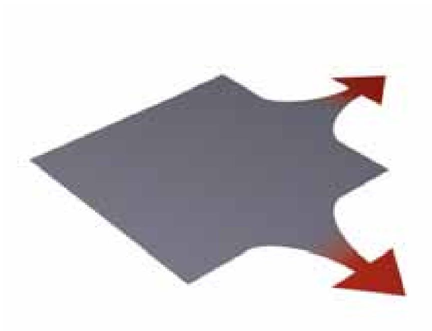
SMC vs. Laminated Steel:



SMC vs. Laminated Steel:

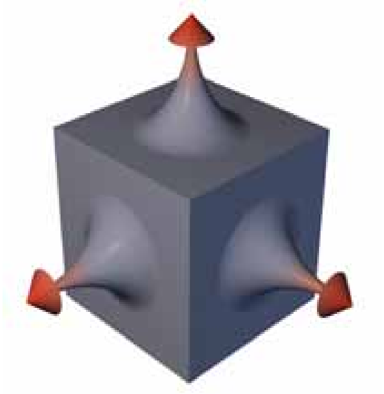
Lamination

- 2D high permeability
- 2D high induction saturation.
- 1D high resistivity
- Low-Medium hysteresis loss



SMC

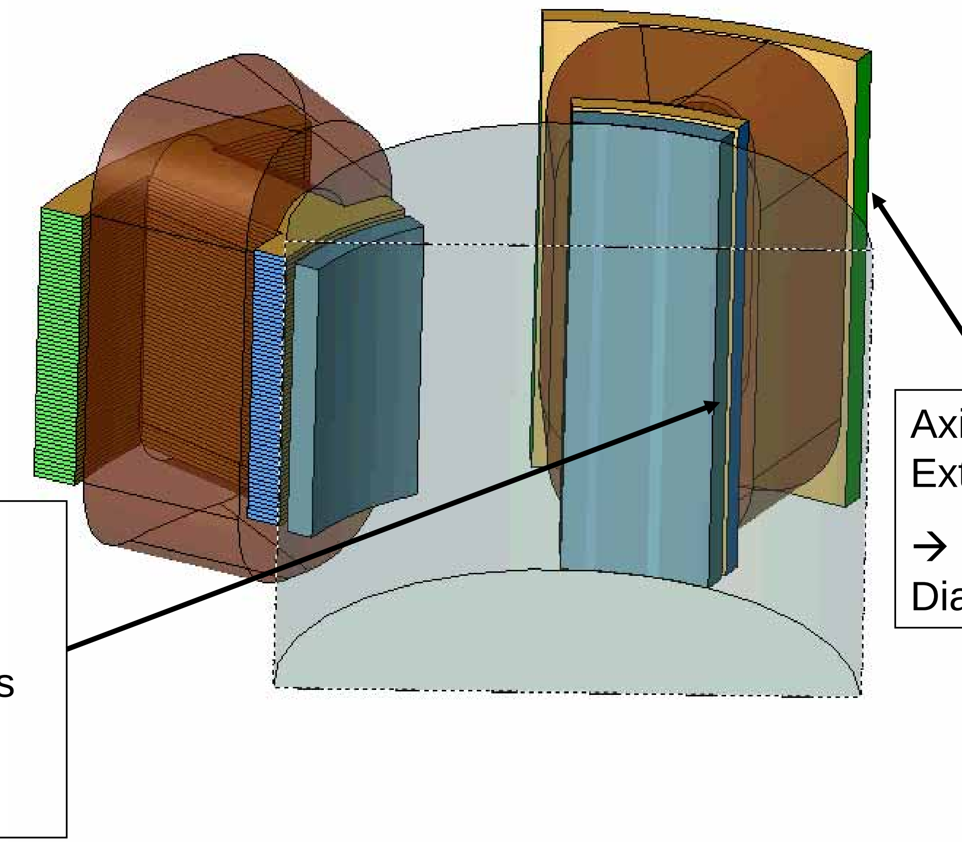
- 3D medium permeability
- 3D high induction saturation
- 3D high resistivity
- Medium-high hysteresis loss



Compared to laminations:

Advantages	Disadvantages
•Isotropic Properties •Net 3D-Shapes •Tight Tolerances •Smooth Surface Finish •Good Mechanical Integrity •Can be Machined •Low Eddy Current Loss •Segmented Designs	•Lower Permeability •Lower Induction-Density Dependent •Higher Iron Loss at Practical Frequencies •Low Strength TRS = 50-100Mpa - Recyclable •Limitations in Component Size

SMC Single Tooth Concept



Longer Air-Gap

→ More Torque or

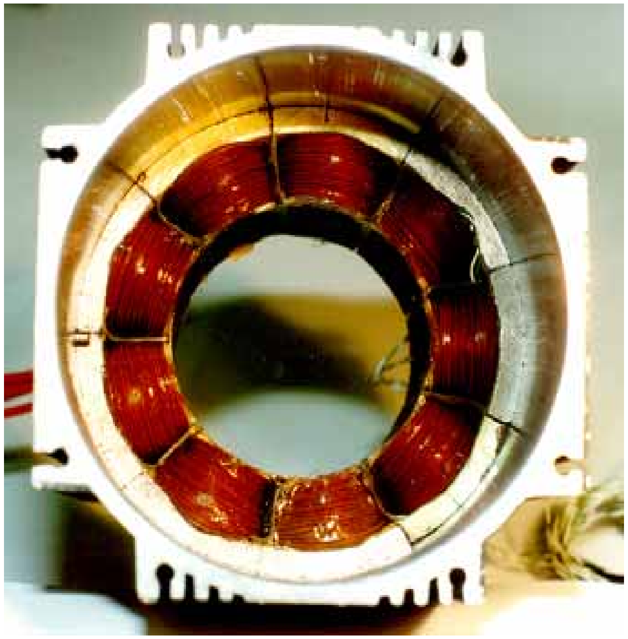
→ Cheaper Magnets or

→ Axially shorter

Axial Extension

→ Reduced Diameter

BLDC Servo Motor



	Laminated	SMC & pre-pressed coil
Overall length (mm)	85	43,5
Thermal limit Torque (Nm) at 3000rpm	2,7	5,1
Torque/volume (Nm/m^3)	3600	13200

BDC ABS Servo Motor – Aisin Seiki, Japan

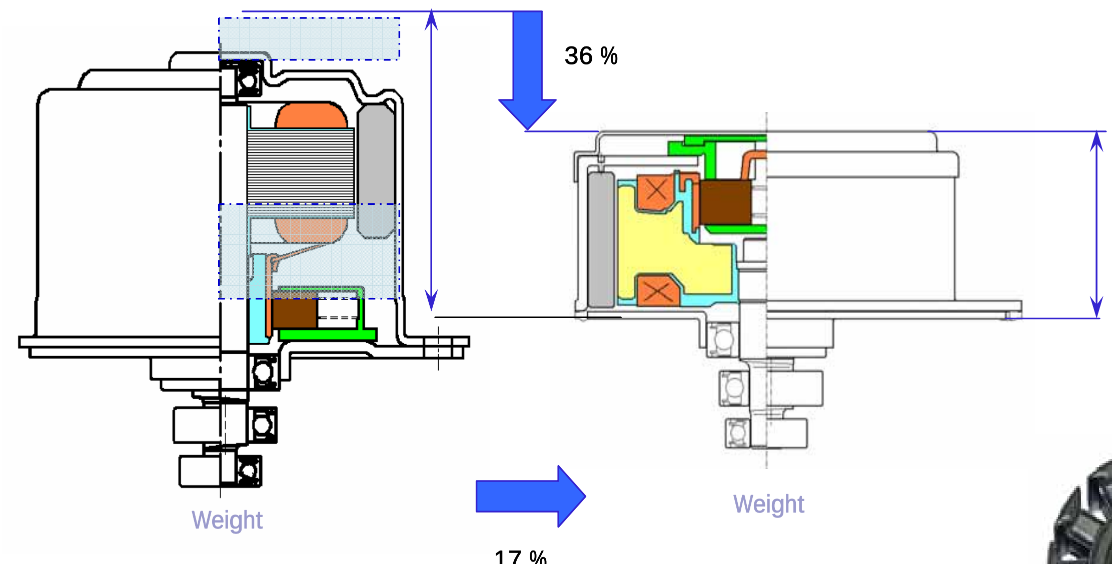
Reduction of low functional space

- Weight reduction
- Compact design
- Less magnets usage
- Complex shaped component reduces number of parts

Courtesy of Aisin Seiki Co Ltd

BDC ABS Servo Motor – Aisin Seiki, Japan

SMC Concept → Downsizing & Weight Reduction



Conventional ABS Motor **New Type of ABS Motor**

PM Exhaust Flange

Material Requirements

- Used for automotive exhaust system manifolds
- Material Requirements
  - **434 Stainless Steel**
  - **Overall density: manifold flange 6.9 g/cm^3 min, outlet flange 7.0 g/cm^3 min**
  - **Part weight: manifold flange 450 g (1 lb.), outlet flange 310 g (0.7 lb.),**
  - **Tensile strength: 450 MPa (65,000 psi) min**
  - **Elongation: 5% min**
  - **Apparent Hardness: 60 HRB min**

PM Exhaust Flange

PM Process Considerations

- Special 3 level PM tooling required to form the domed shape while achieving a minimum 6.9 g/cm^3 density
- Use of high temperature sintering (>1260 °C, 2300 °F) needed to achieve the required final density, tensile strength, and elongation
- All part features are formed during compaction, including the bolt holes
- Following pressing and sintering the only secondary operation needed is deburring

PM Exhaust Flange

Benefits of using PM

- The manifold flange replaced a two piece stamped and welded assembly that was prone to leakage
- The use of the PM's net shape capability allowed for the use of a higher alloy content that is more corrosion resistant and has higher strength at elevated operating temperatures
- The PM stainless steel parts are warranted for 100,000 miles

Stainless Steel Automotive exhaust flanges and HEGO bosses

- Provide opportunity to save material cost by almost 100% material utilization
- PM allows integration of design features
- Typically 400 series

Stainless Automotive Exhaust Flanges

PM allows net shape features like the “Tulip Flange”

Other design features, such as grooves can also be manufactured to net shape

Reference Sources

- Much of the information on the materials and concepts covered in this presentation can be found in:
  - www.pickpm.com
  - Global Powder Metallurgy Property Database: www.pmdatabase.com
  - Powder Metallurgy Design Solutions
  - Powder Metallurgy Design Manual
  - MPIF Standard 35, Materials Standards for PM Structural Parts