Lectures #5

29 September 2020

Powder Metallurgical Processing

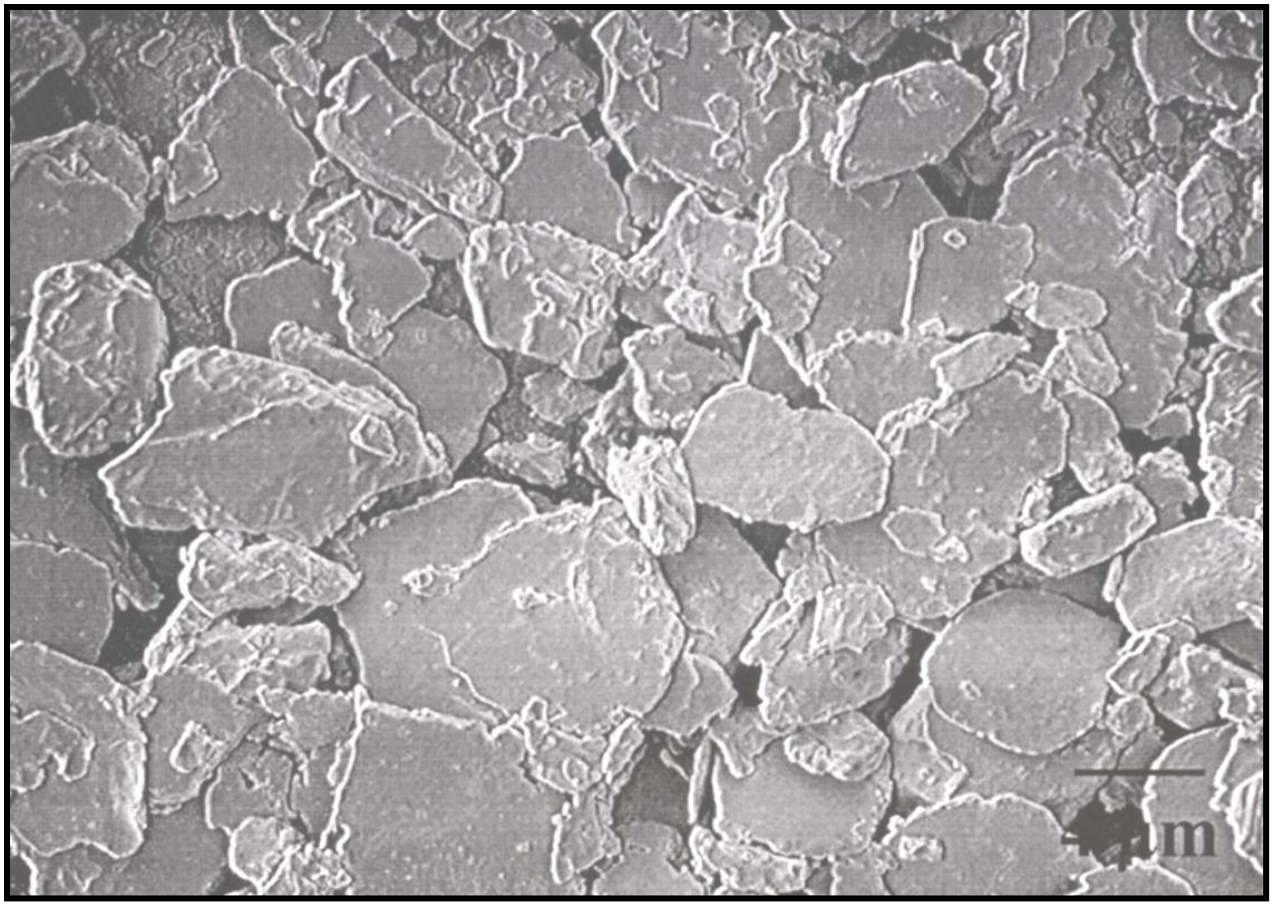
Powder Metallurgical (P/M) Processing

- net-shape manufacturing process
- refractory materials
- complicated shapes with high precision
- ease of automation
- low-cost, high production quantity
- novel compositions
- unique microstructures

KEY PROCESS STEPS

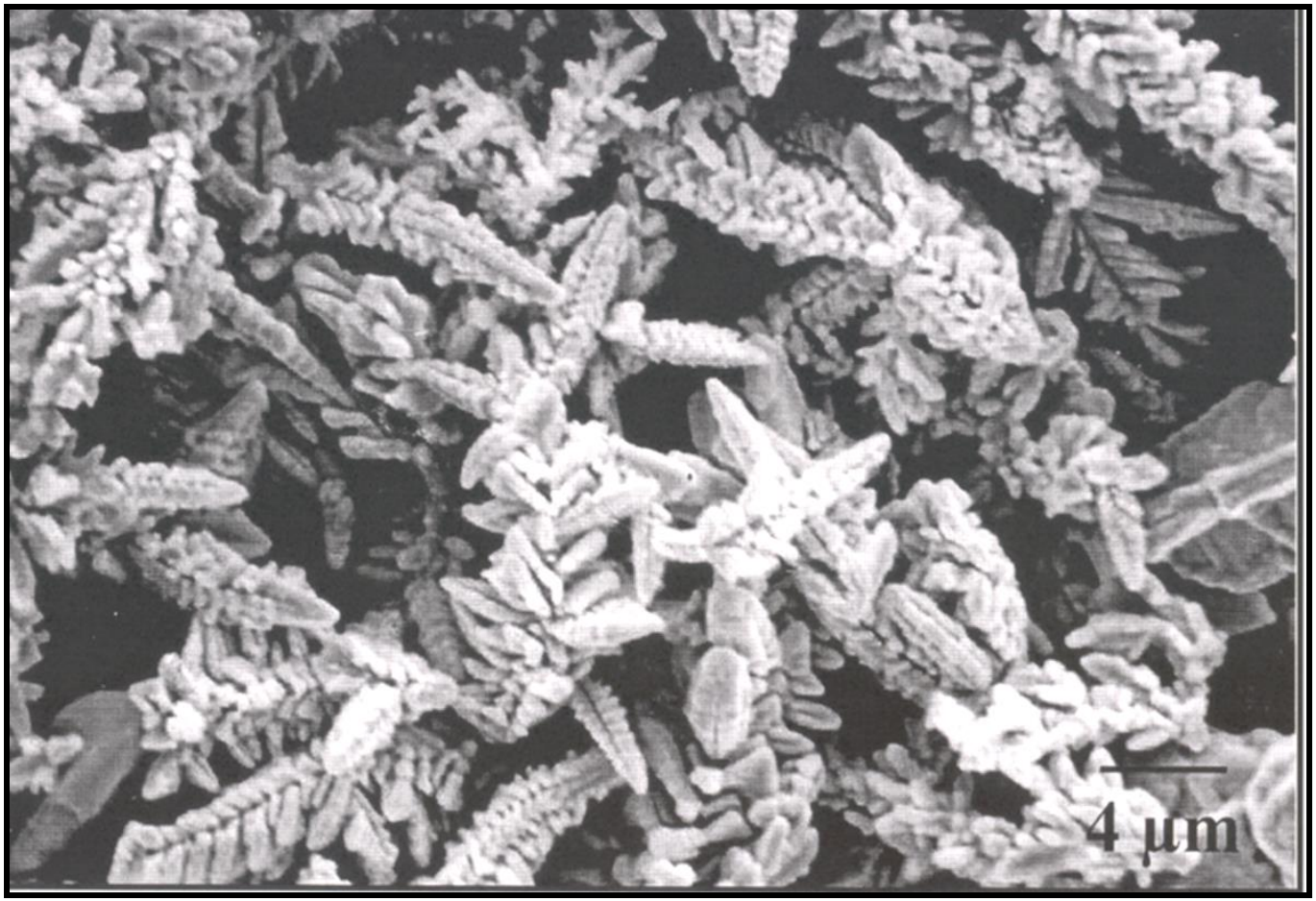
- ❑ ***Powder Processing***
- ❑ ***Compaction***
- ❑ ***Sintering***

Titanium Powder



Fabrication Route: **Milling**

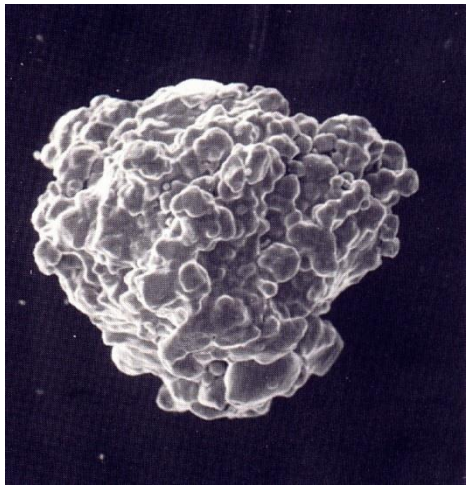
Copper Powder

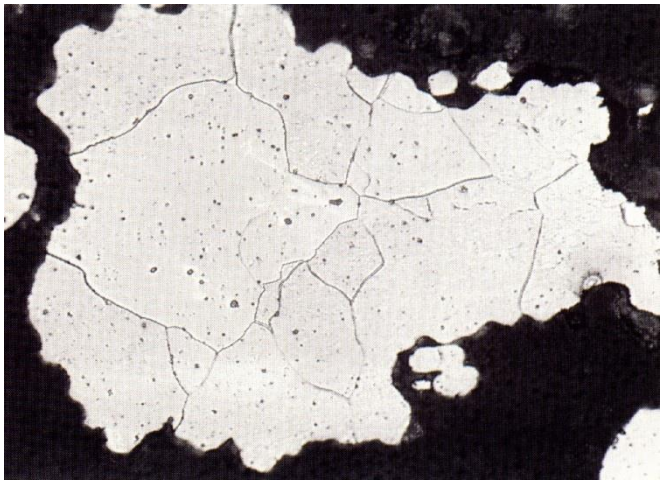


Fabrication Route: **Electrolysis**

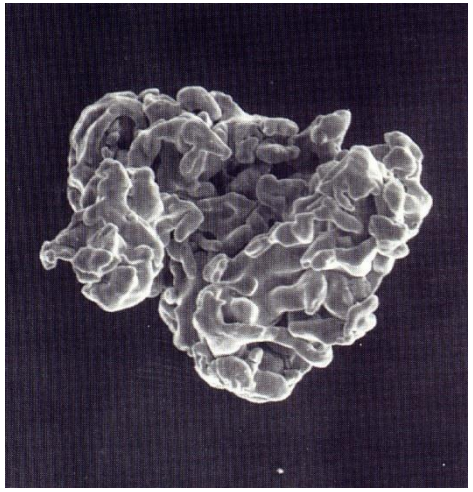
Effect of Processing Technique on Shape and Structure of Iron Powder

- **atomized**

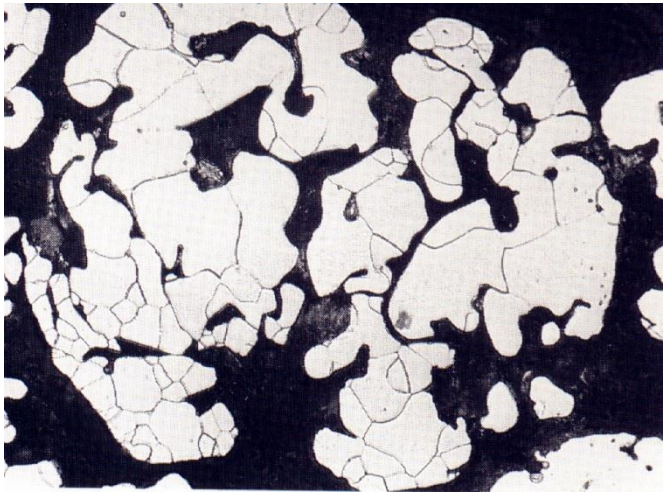




- **reduced**



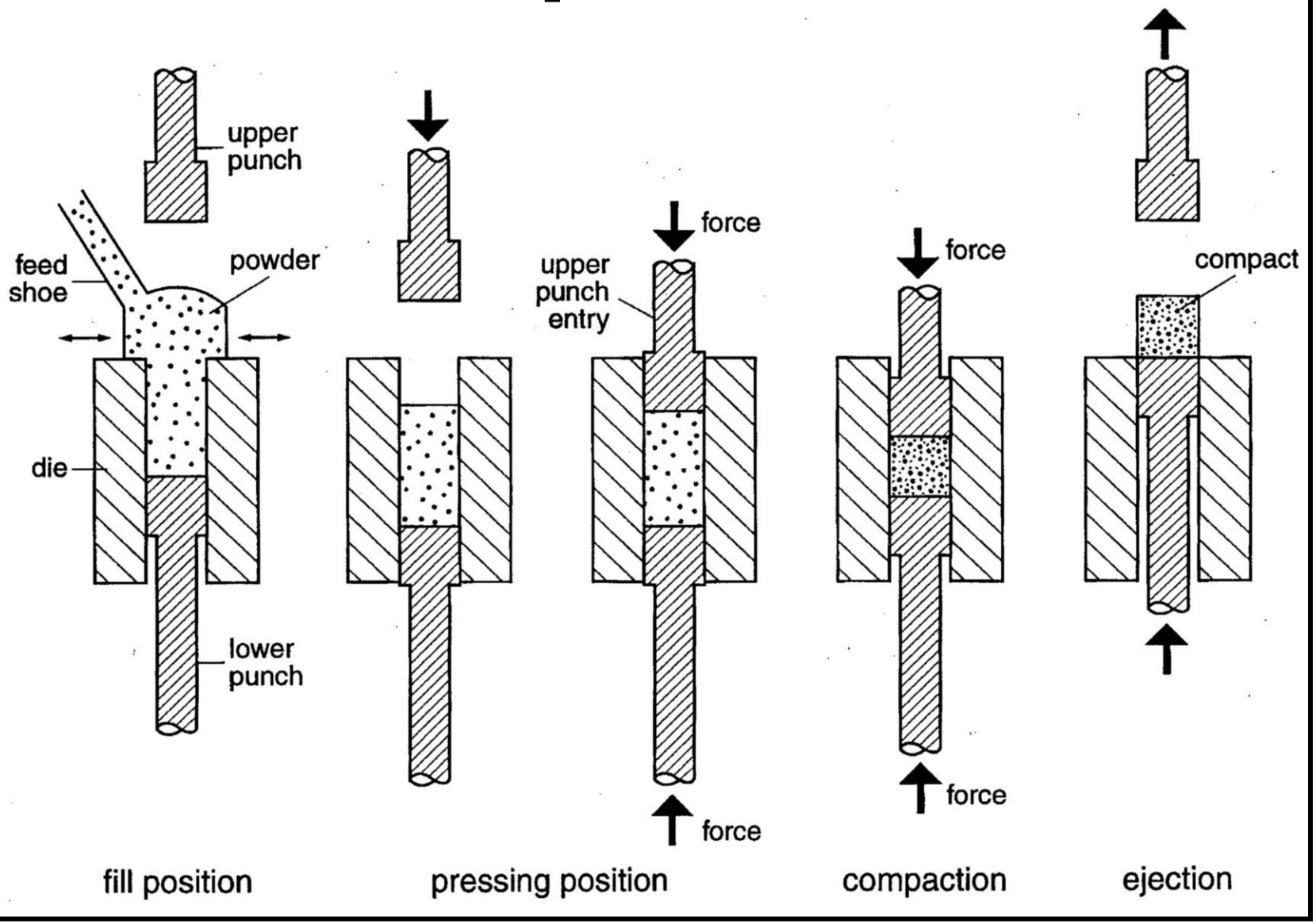
x 200

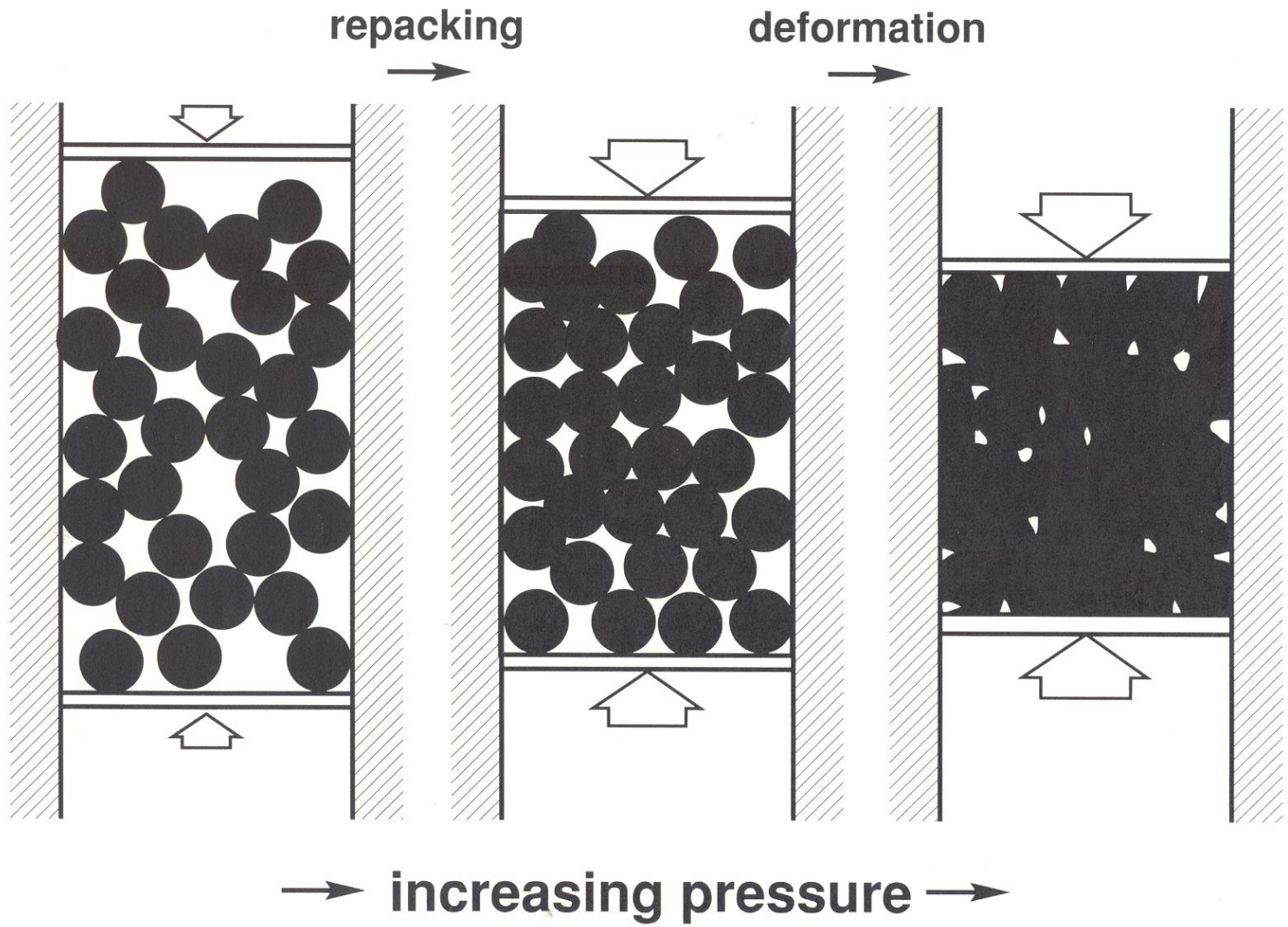


x 400

supplier: Kawasaki Steel

Compaction of Powders




repacking
deformation
increasing pressure

Sintering

A thermal treatment for bonding particles together into a coherent, predominantly solid structure via mass transport events that occur largely at the atomic level. The bonding leads to improved strength and lower the system energy

Variants

- Solid-State Sintering
- Liquid Phase Sintering

SINTERING

Thermal treatment for **bonding particles together into coherent, solid structure** via mass transport events that occur largely at the atomic level

Loose powder

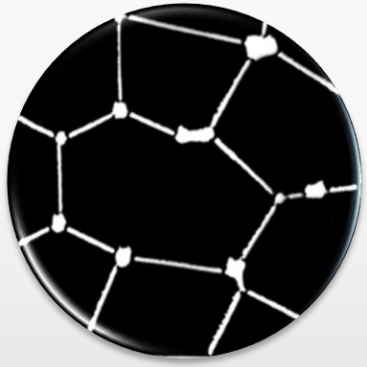
- Point contact

Initial stage

- formation of necks between Particles
- Pores are angular

Intermediate stage

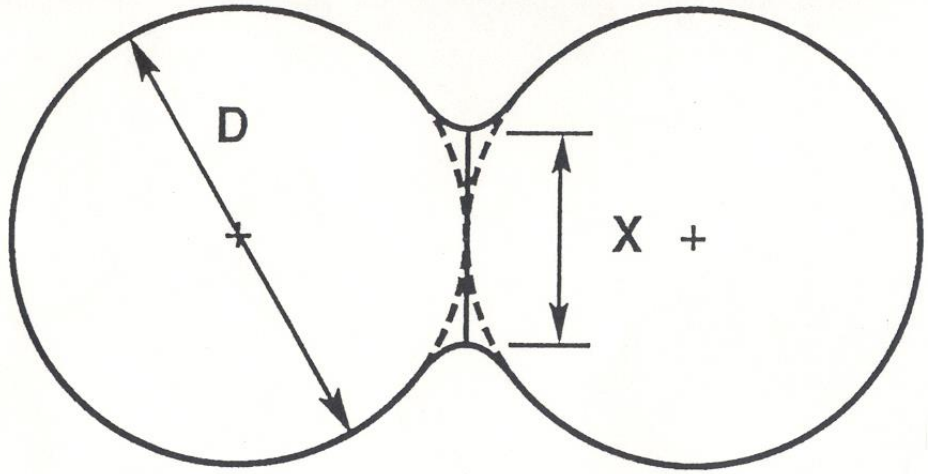
- Pore rounding
- Densification, and
- Grain growth



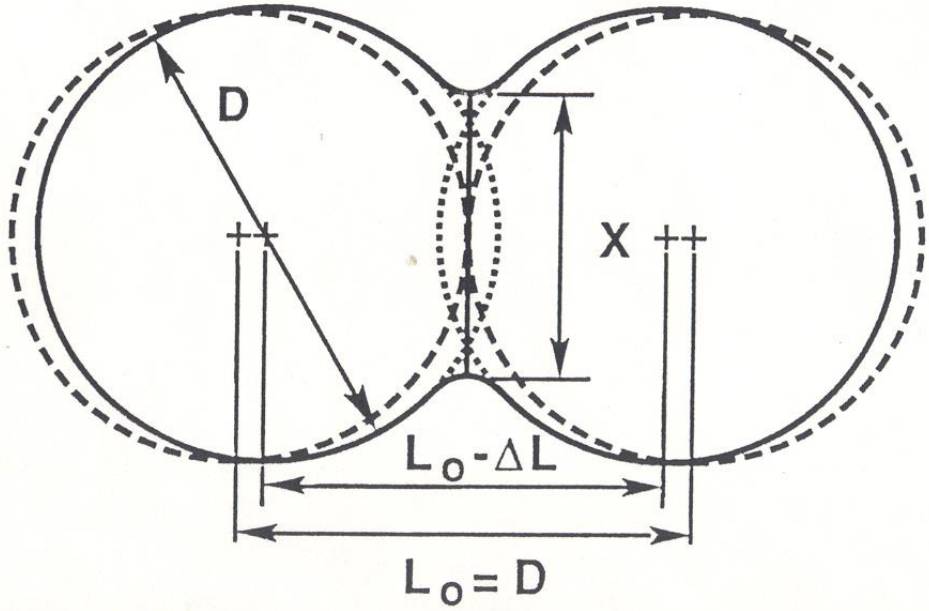
Final stage

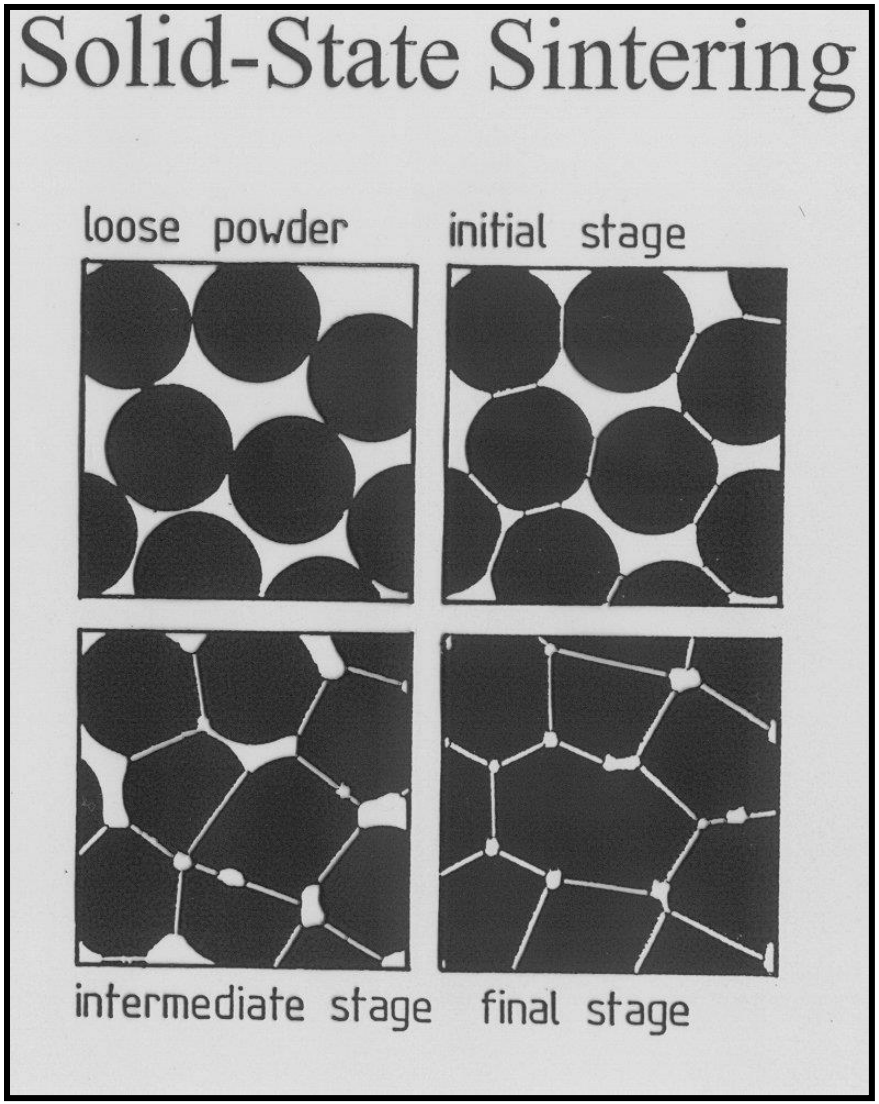
- Formation of few isolated, spherical pores
- Enlarged grains

Before Sintering
point contact



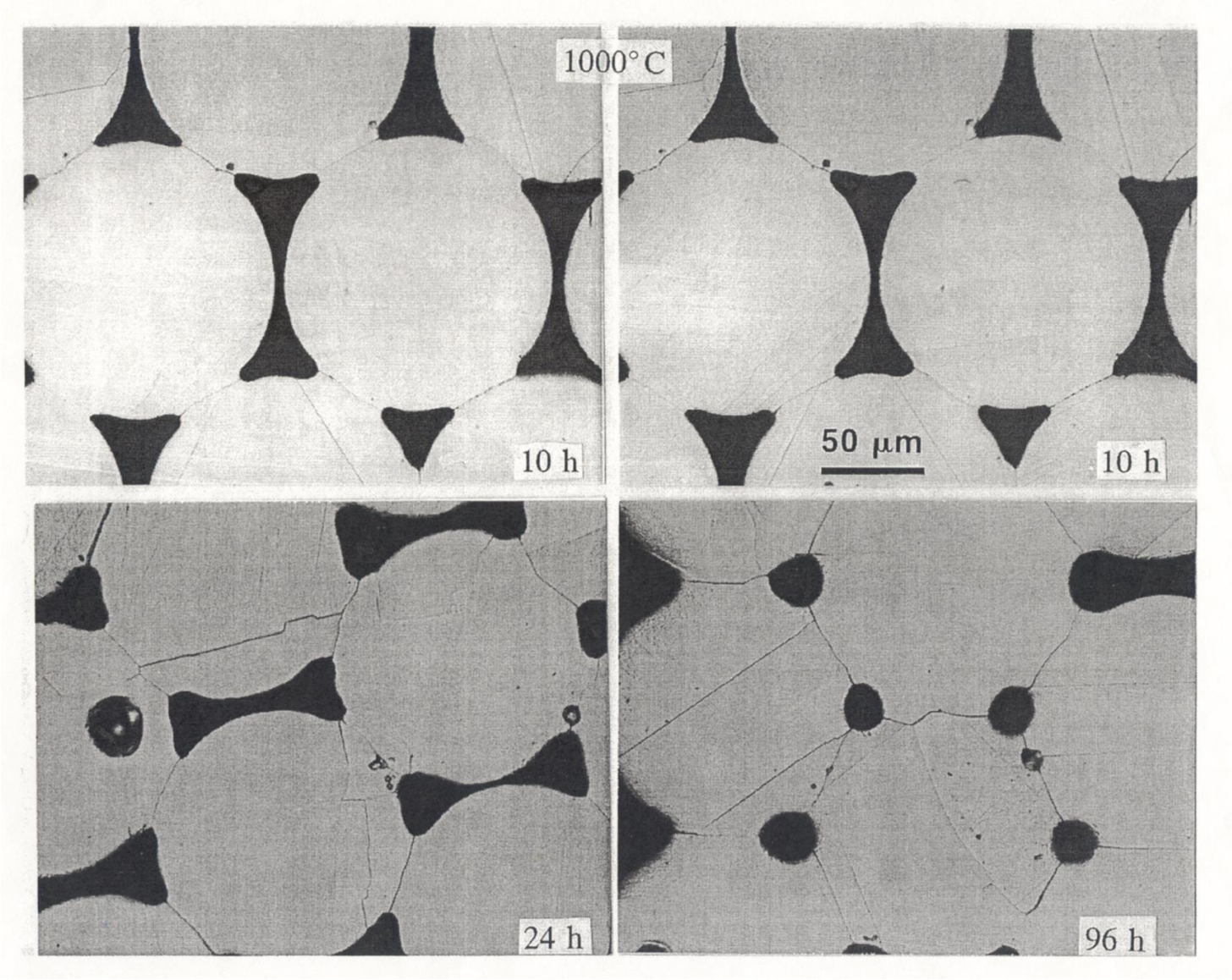
After Sintering
Formation of inter-particle bonds
Neck
center-to-center distance between the two particles shown in fig. reduces

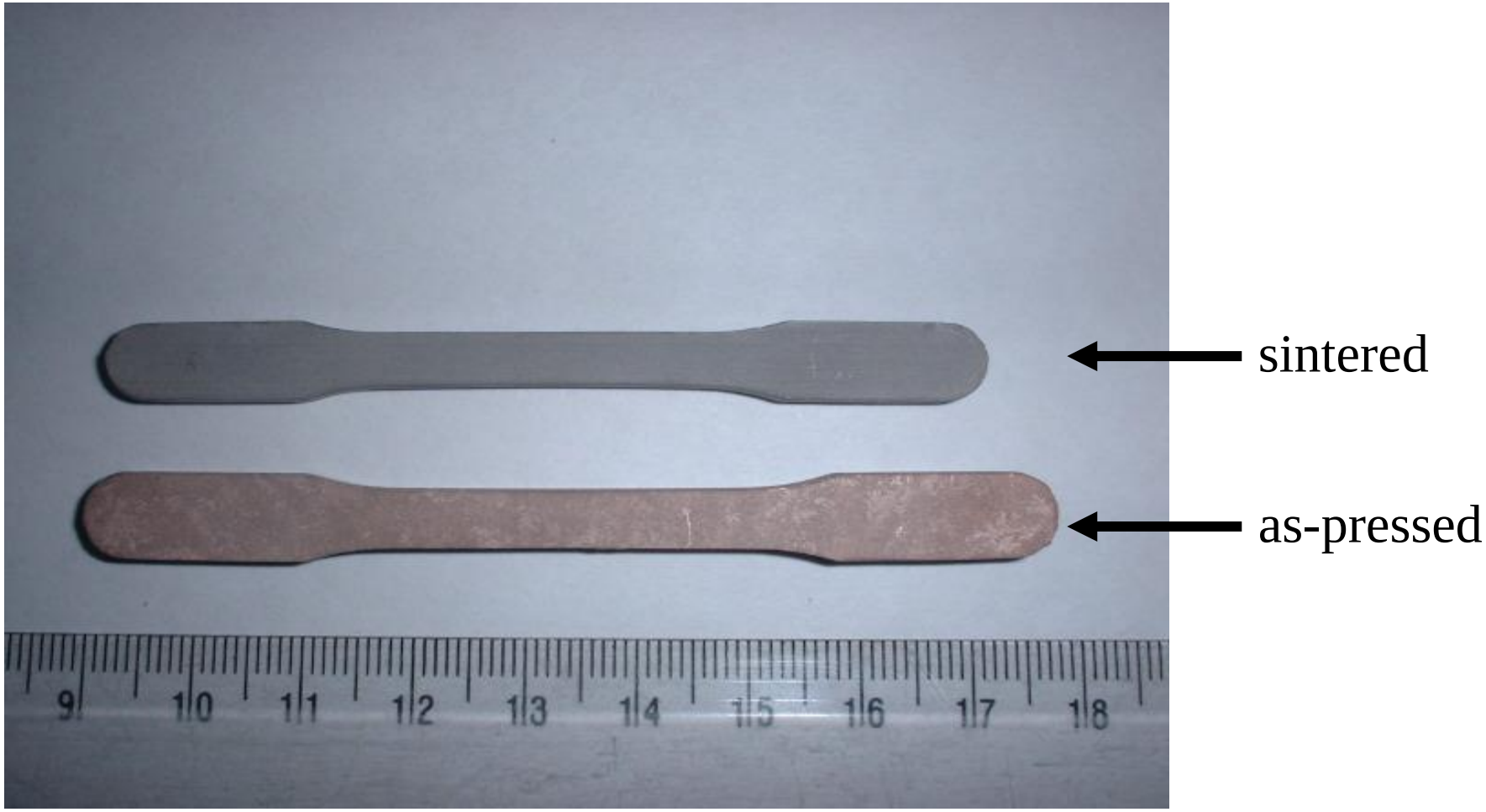




Initial stage: formation of interparticle neck
intermediate stage: transition occurs from open porosity to closed porosity. Typically, when the overall porosity in the compact is less than 8%, the pores are predominantly closed type
final stage: elimination of closed pores.

Effect of sintering time on densification of monosized, spherical Cu powder.
Note that as the sintering time increases (temperature is constant: 1000°C), porosity gradually reduces.
In case the sintering time is kept the same, similar results can be achieved by increasing the sintering temperature




sintered
as-pressed
9
10
11
12
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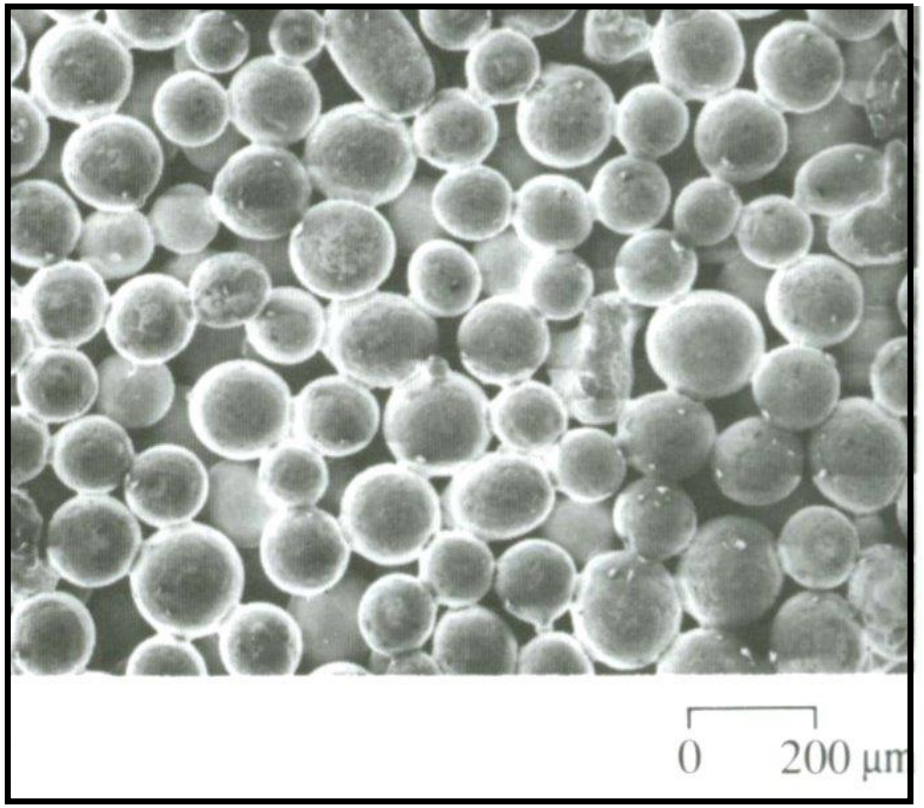
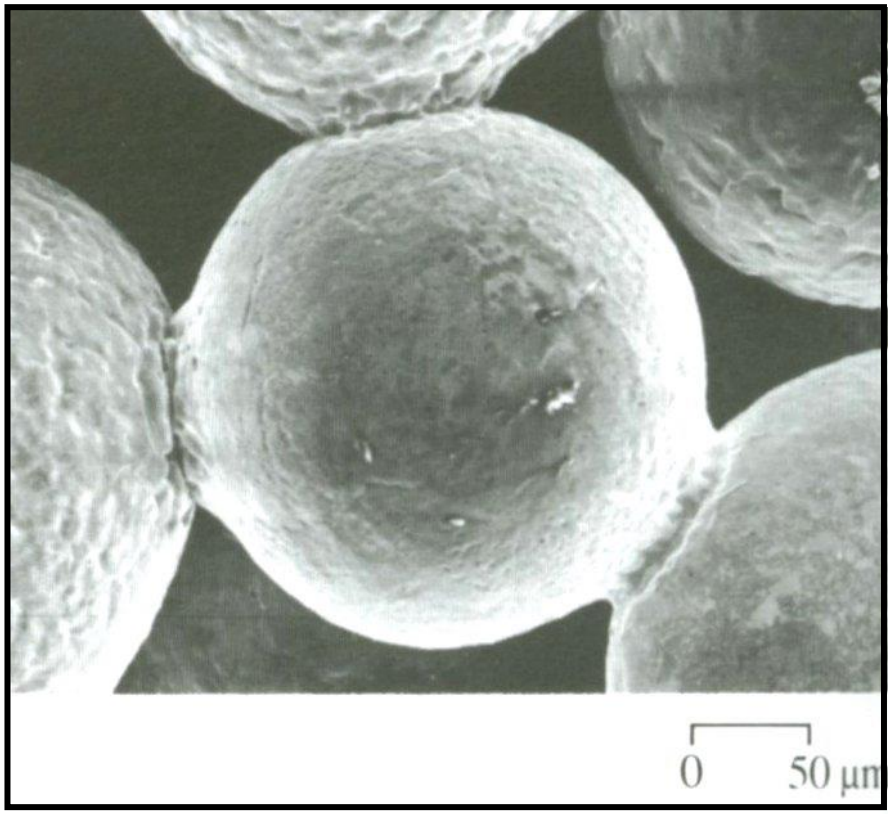
18

Self-Similar Volumetric Shrinkage during Sintering

Green Sintered

Pressureless Sintered Filters





POWDER METAL PART USAGE ON AUTOMOBILES

HARDWARE
- Airbag hardware
- Air conditioning compressor clutch hub
- Bearings
- Door hinges
- Electric motor cores and armatures
- EGR base plate
- Fasteners
- Gears — electric remote windows
- Headlight activator gear
- Hinge brackets — auto roof
- Ignition key lock gear
- Lock parts (striking plate, latch)
- Pinion gear — door windows
- Rearview mirror mount
- Signal light lever
- Speedometer gears
- Starter motor pinion gear
- Swash plate — air condition compressor
- Tachometer sensing ring

SEATS
- Adjustment racks
- Adjustment levels
- Adjustment worm gears
- Recliner parts
- Safety belt locks

SUSPENSION
- Ball joint bearings
- Clips
- McPherson strut rod guides
- Shock absorber compression valve
- Shock absorber cylinder ends
- Shock absorber pistons
- Shock absorber rod guides

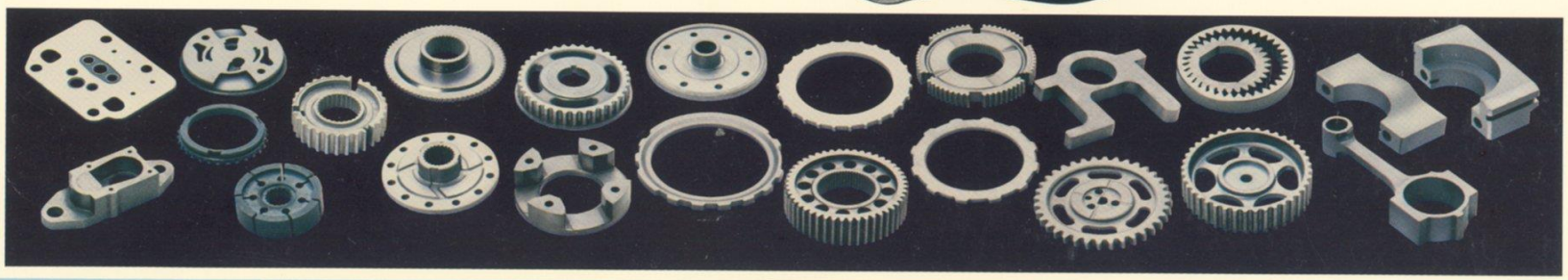
BRAKES
- ABS sensor rings
- Adjustor nuts
- Adjustors
- Brake lock — master cylinder
- Pistons

STEERING
- Column collar
- Column gears
- Column lock bolt
- End plate
- Gear shifting and locking lever
- Inner cylinder bulkhead
- Locking wedge
- Passive restraint locking pawls
- Rack bearing
- Rack guide bushing
- Tilt steering wheel ratchet lever
- Torsion bar bushing

ENGINE
- Air pump bearing retainer
- Alternator heat sink
- Camshaft lobes
- Camshaft retainer
- Camshaft holddown bracket
- Camshaft sprocket
- Connecting rods
- Crank shaft sprocket
- Cranking motor planetary pinions
- Cranking motor pole piece
- Cranking motor plunger stop
- Distributor pole pieces
- Distributor gears
- Emission control plate
- Engine balance shaft
- Exhaust flange
- Fuel injector pump
- Fuel pump eccentric
- Gerotor-type oil pumps
- Main bearing caps
- Oil pump gears
- Pollution control housing
- Power steering pump rotors, cams, side plates, vanes, slippers
- Rear rotor plate
- Rocker arm balls
- Rocker arm fulcrums
- Sensor Rings
- Tappet valve guides
- Throttle cam
- Valve lifter guides
- Valve seats and inserts
- Water pump hubs
- Water pump impeller
- Water pump flange
- Water pump pulley

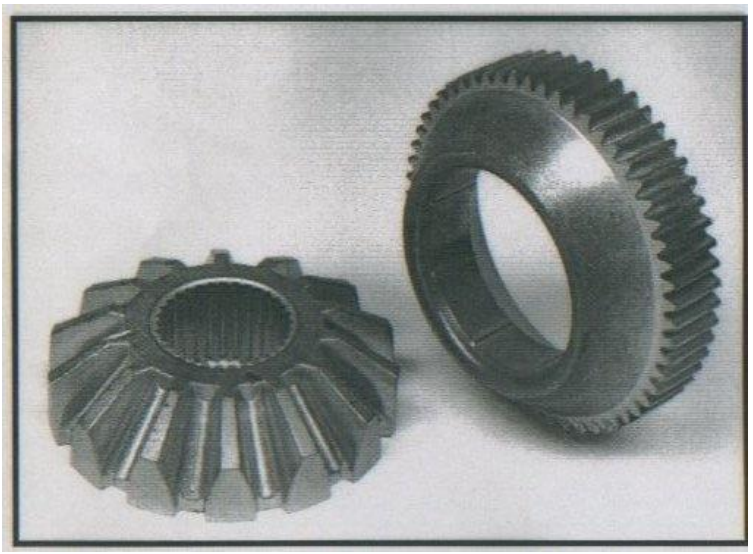
WINDSHIELD WIPERS
- Drives
- Motor flux rings

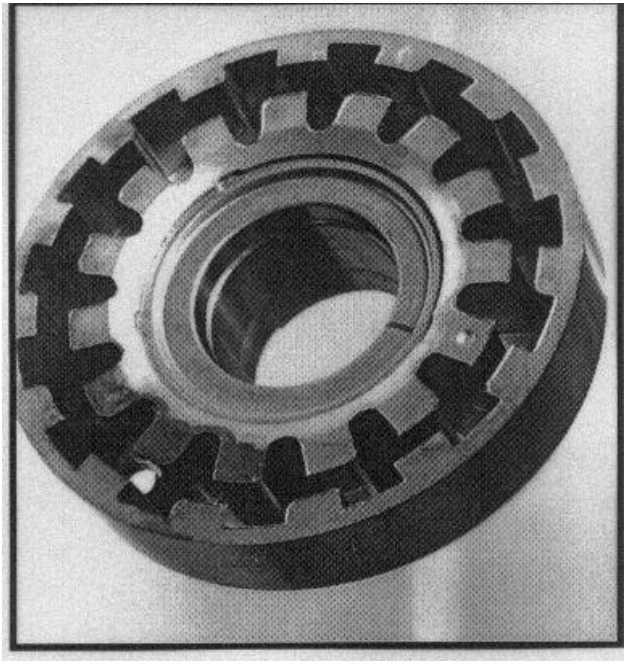
TRANSMISSION
- Cam stator, torque converter
- Clutch hub and adjusting ring
- Clutch pressure plates
- Clutch releases
- Converter clutch races (outer/inner)
- Converter turbine hub
- Kick down lever
- Lock-up clutch collar
- Lock-up converter cams
- Oil pump crescent gears
- Oil pump gears
- Oil pump gerotors
- Oil pump rotor and slide
- Overrunning clutch races
- Parking gear
- Ring gears
- Shift fork, reverse gear
- Standard transmission detent and guide
- Strut
- Sun gear spacer
- Synchronizing hub and locking keys
- Synchronizer interlock sleeve
- Synchronizer blocker rings
- Torque converter hub
- Four-Wheel Drive
  - —Planetary gear carrier
  - —Drive and driven sprockets
  - —Inner mode hub
  - —Main shaft hub
  - —Clutch housing



P/M Connecting Rods

Gears





Powder Fabrication Techniques

Reduction

e.g. reduction of Fe_3O_4 to get ‘sponge’ Fe powder. It has internal porosity

Milling

e.g. Ti powder. Milled ductile powders have often ‘flaky’ morphology

Variant: **Mechanical Alloying** used for making ‘alloy powders’ by milling various constituent powders together

Electrolysis

e.g. electrolytic Cu powder. Has ‘dendritic’ morphology

Atomization of alloy/metal melt

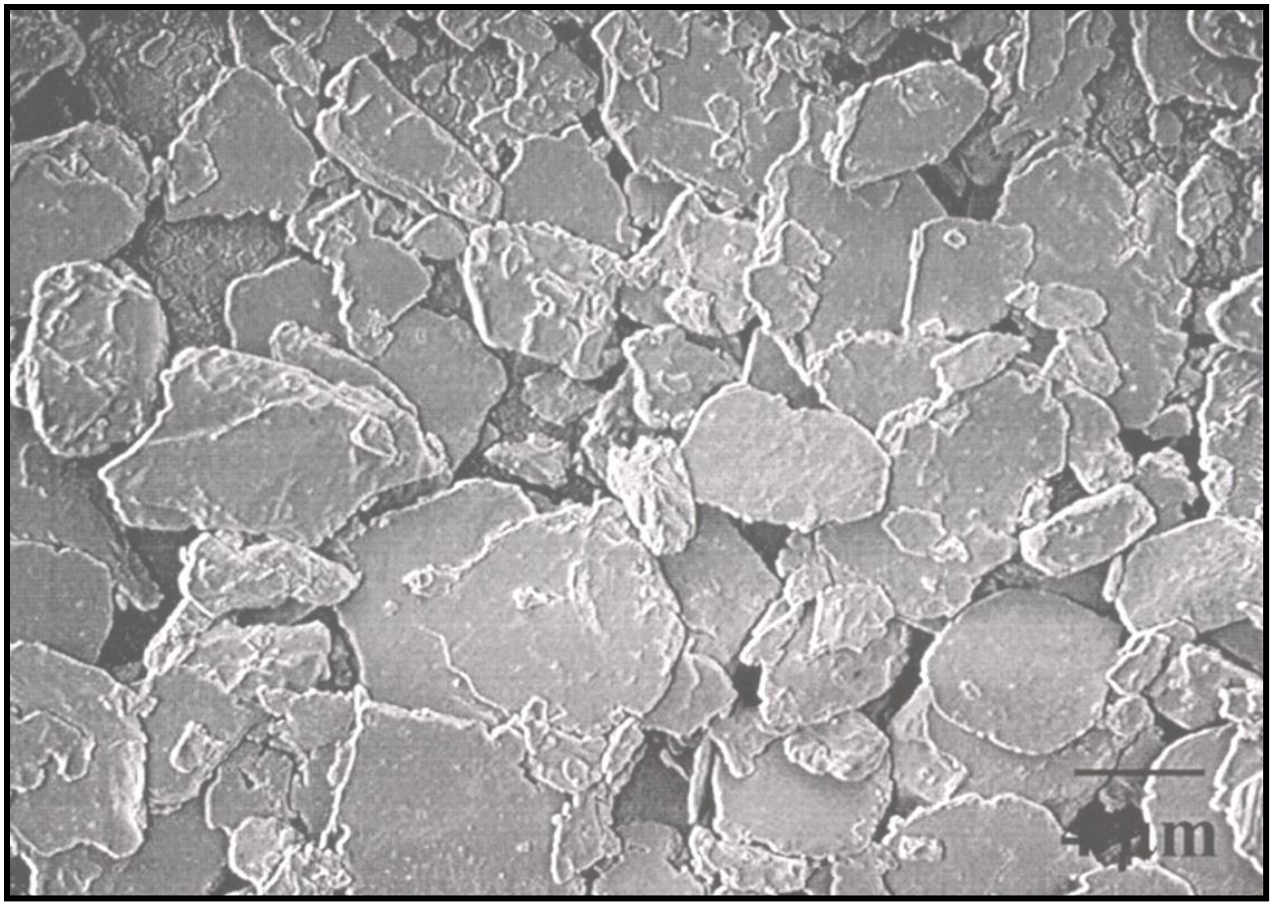
Water Atomization:

use water jet to disintegrate melt into small droplets that solidify to form powder. The powders are irregular shaped (similar to reduced powder) BUT have no internal porosity (unlike sponge powders fabricated by reduction process)

Gas Atomization:

use inert gas to disintegrate melt. The powder has rounded/spherical shape

Titanium Powder



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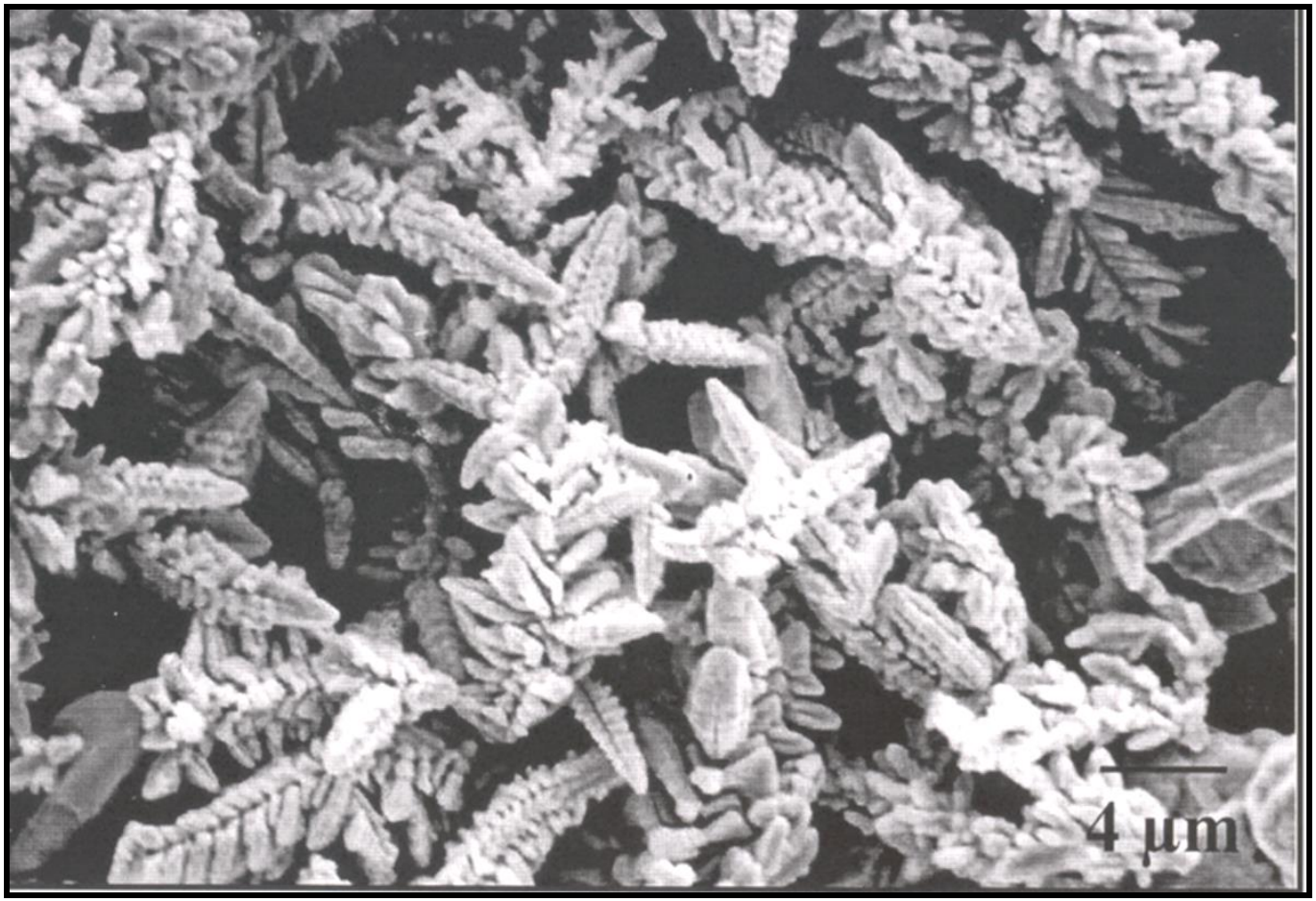

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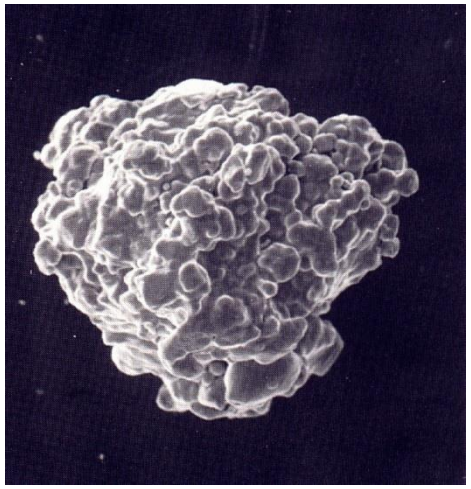

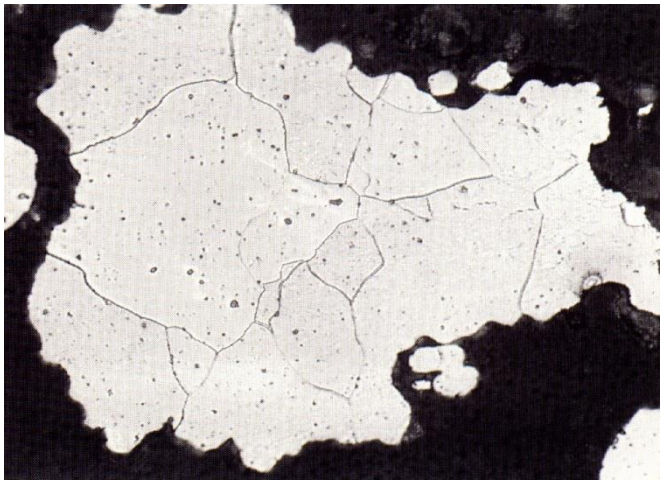

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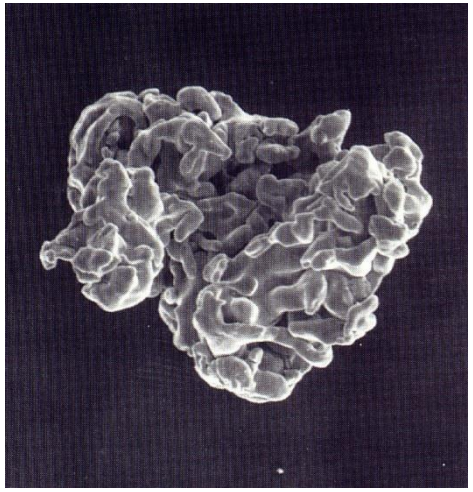
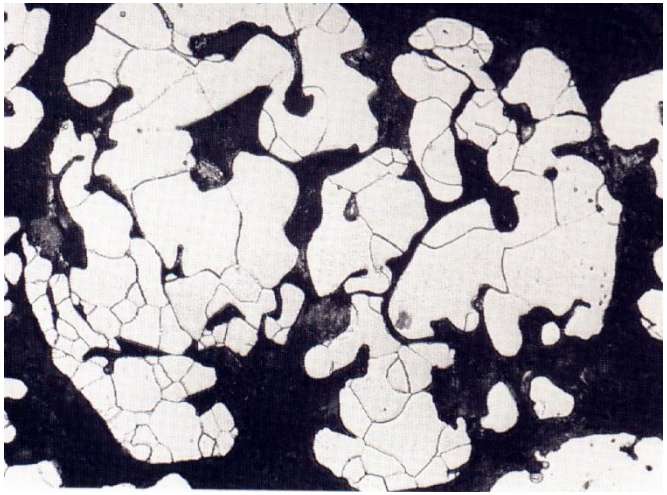


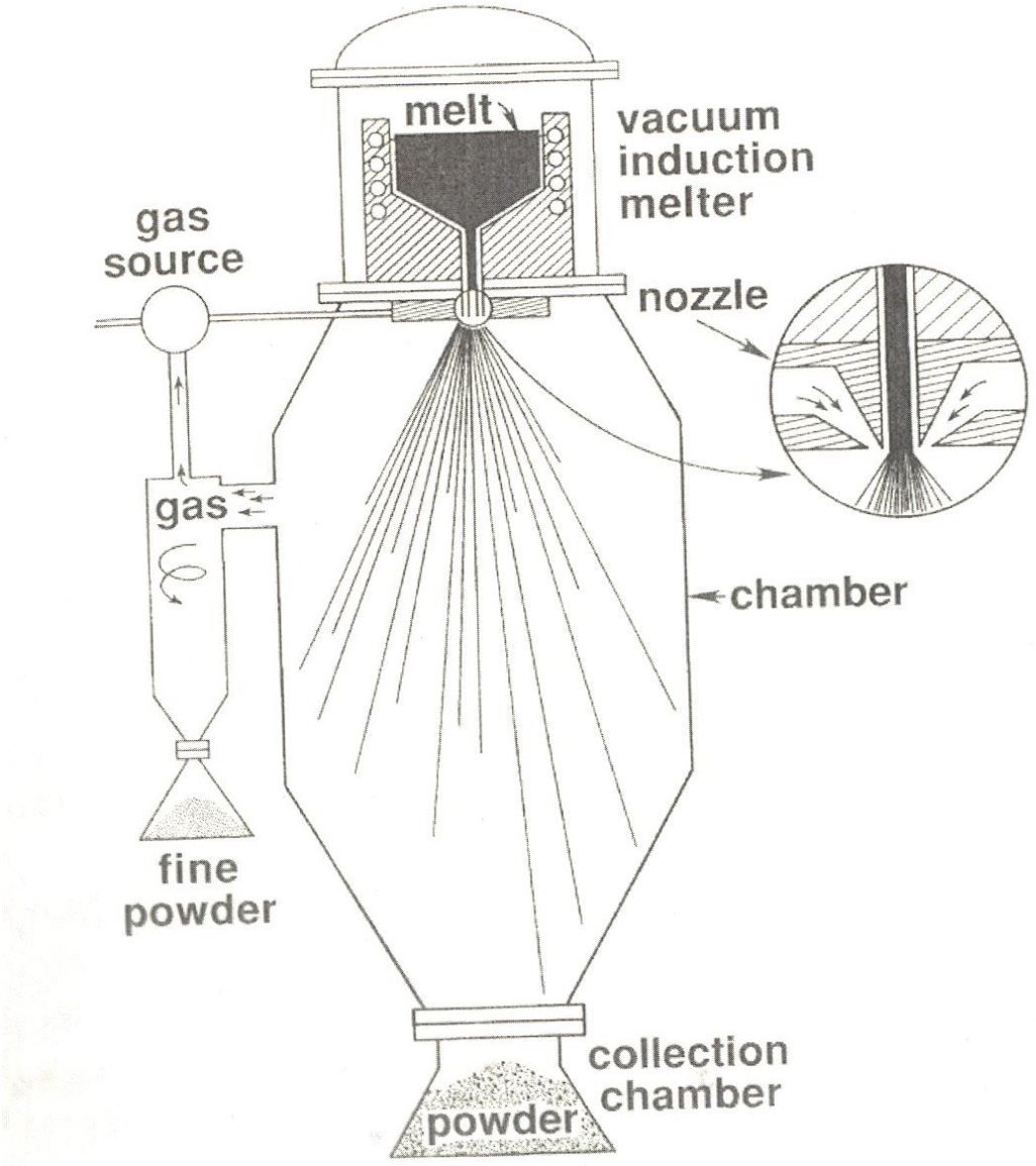
x 200



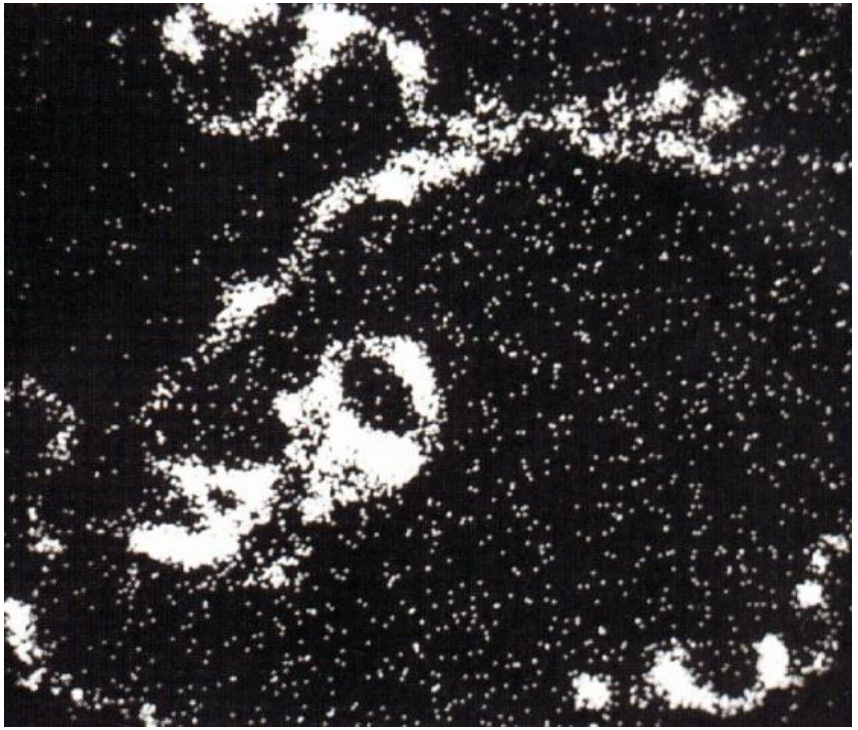
x 400

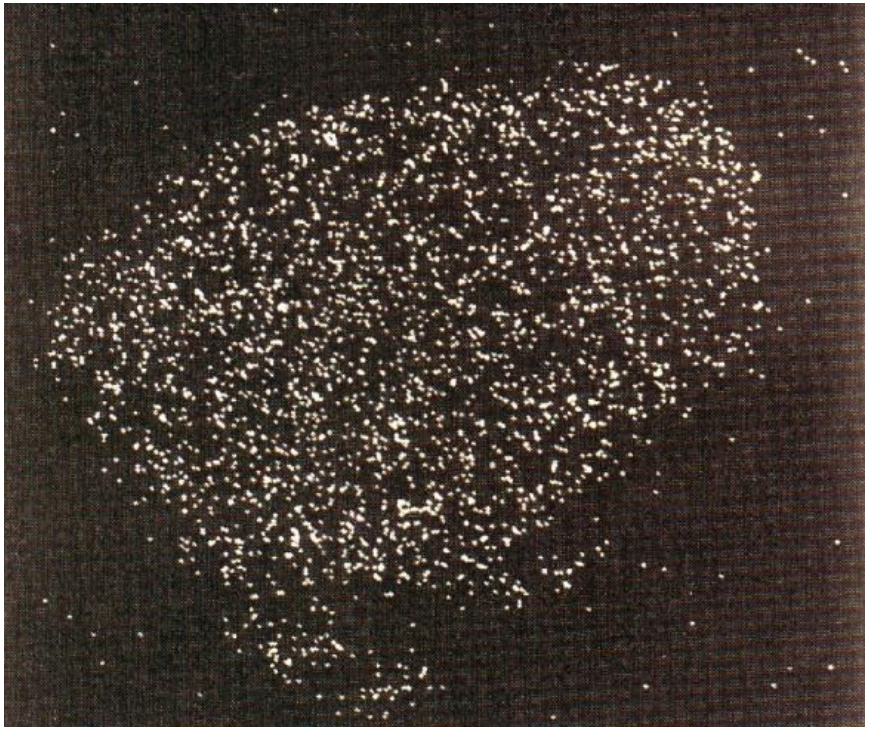
supplier: Kawasaki Steel

Gas Atomization



Alloyed Fe Powder



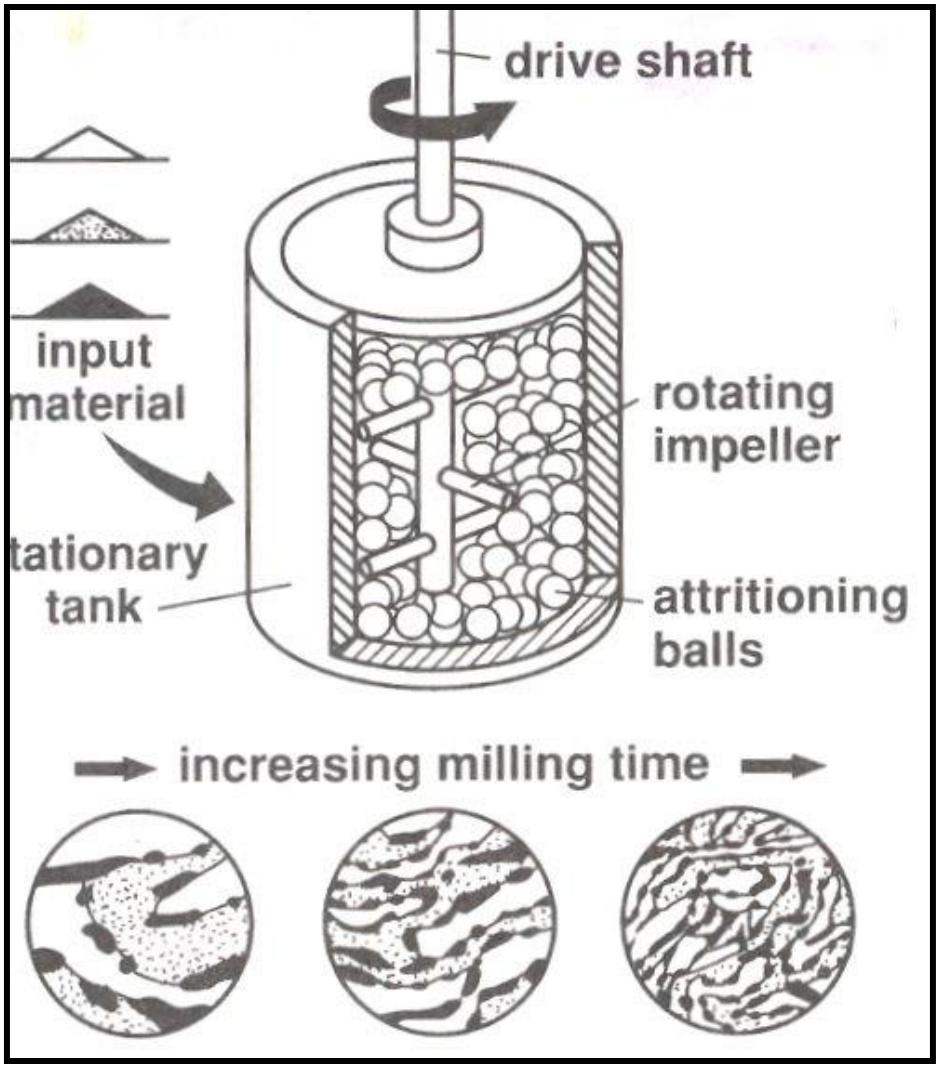


- **partially alloyed**

- **pre-alloyed**

supplier: Kawasaki Steel

Mechanical Alloying



PRESSING AND SINTERING

PROCESS

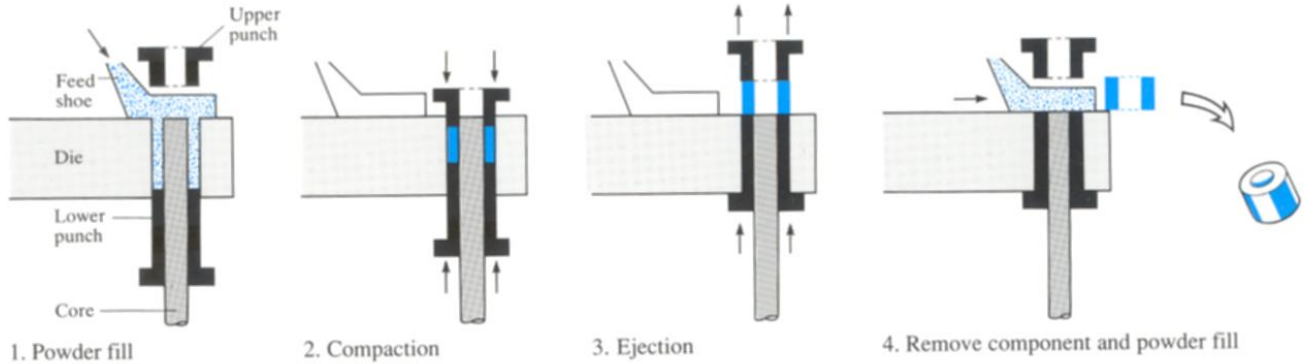
Powder processing
Powder is pressed in closed dies to form a green compact which is then sintered at elevated temperature.

SHAPE

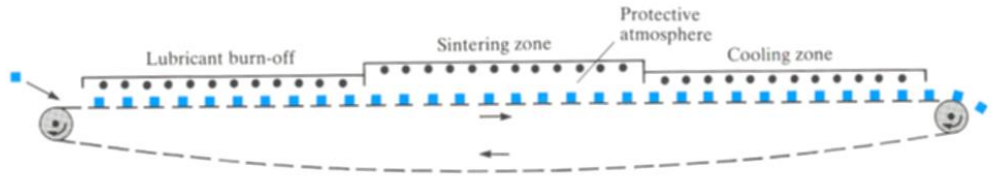
3D solid
Solid shapes without re-entrant angles.

MATERIALS

All materials
Mainly used for metals and ceramics.



Sequence of operations for production of cylindrical bearing



Sintering operation

CYCLE TIME

Dictated by sintering mechanisms but normally long.

QUALITY

Elimination of porosity and dimensional stability on sintering mutually exclusive. Density variations in product inevitable.

FLEXIBILITY

Tooling dedicated. Sintering equipment not dedicated.

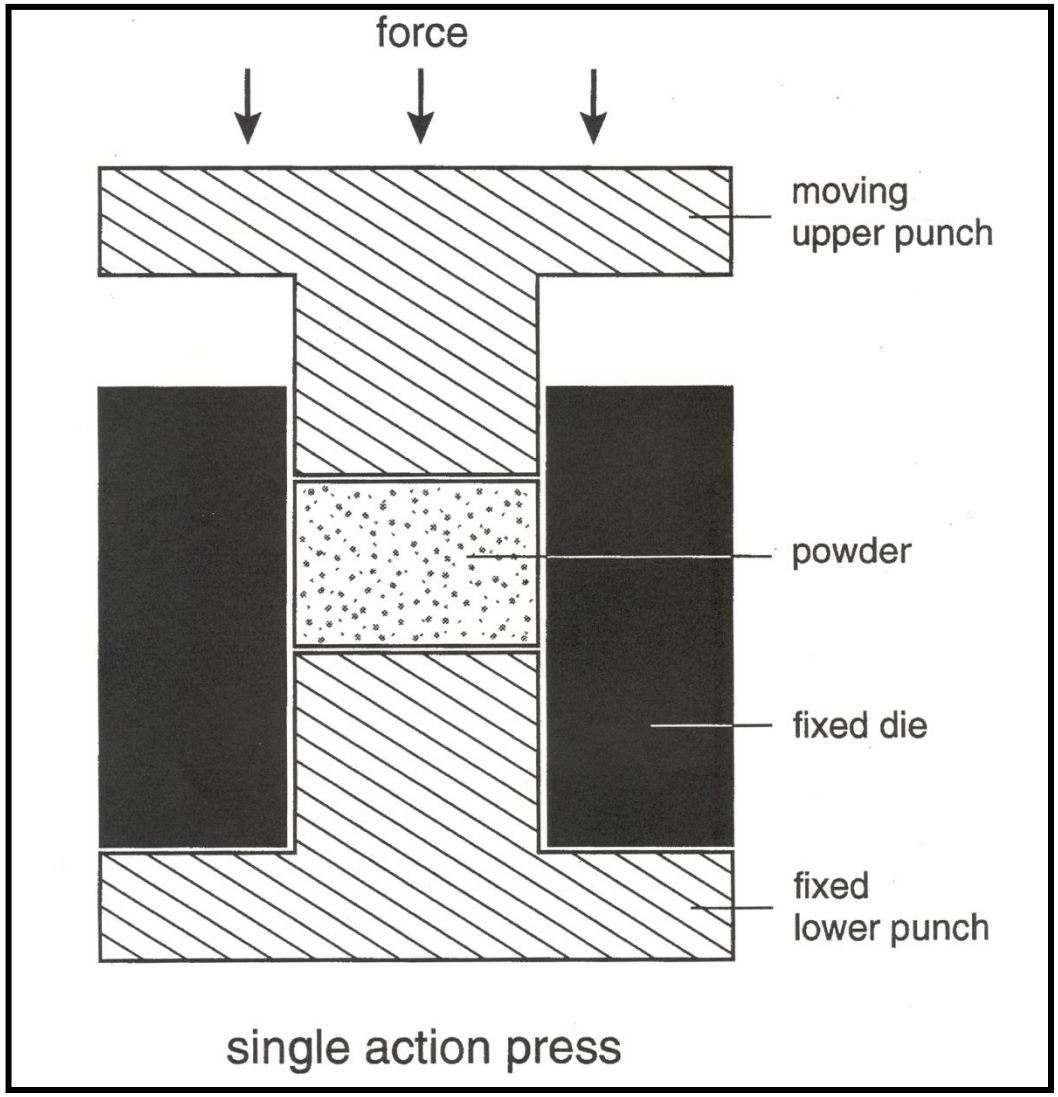
MATERIALS UTILIZATION

Near net shape process. 100% material utilization.

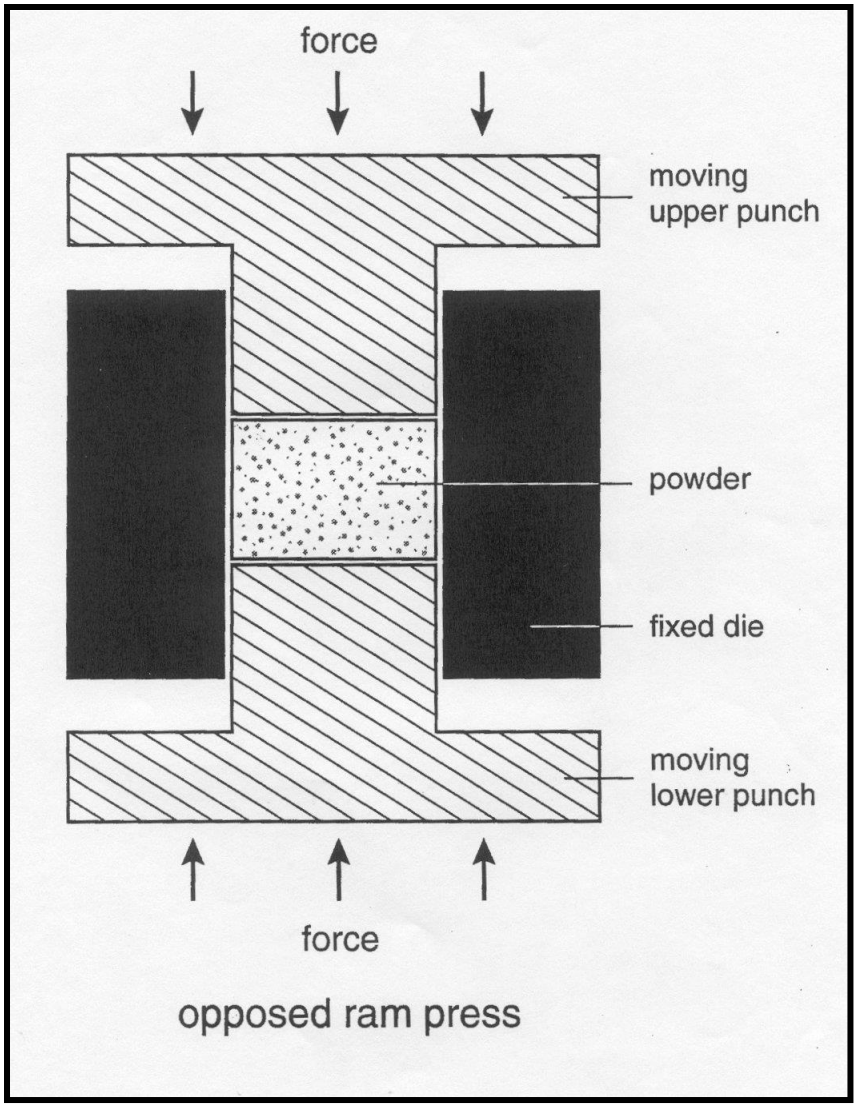
OPERATING COST

Machinery and dies relatively costly particularly if automated.

Single Action Compaction



Double Action Compaction



ISOSTATIC PRESSING

PROCESS

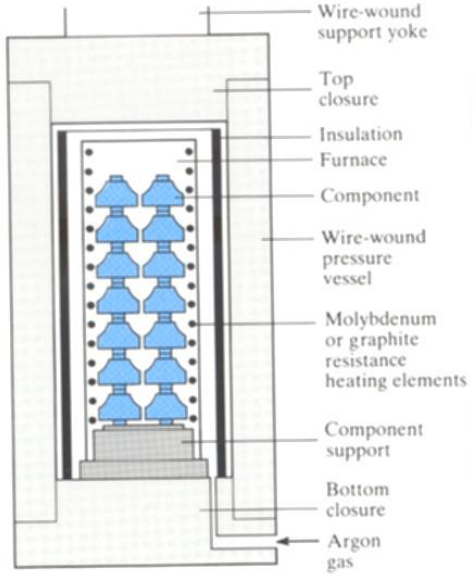
Powder processing
Powder is placed within a deformable container and subjected to hydrostatic pressure. CIP produces green compact, HIP presses and sinters simultaneously.

SHAPE

3D bulk
Solid shapes. Small re-entrant angles possible

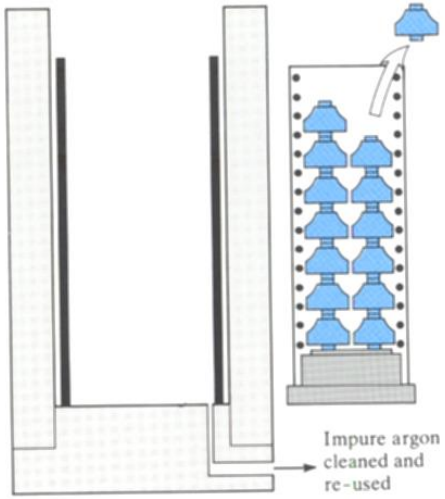
MATERIALS

All materials
Mainly used for metals and ceramics

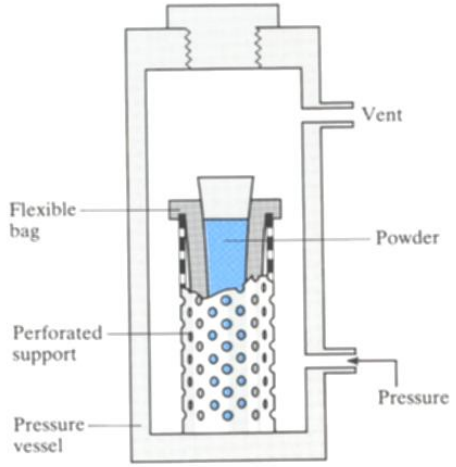


Hot isostatic pressing (HIP)

1. Load components into furnace which is placed into pressure vessel. Raise temperature and pressure simultaneously and hold.



2. Cool, release gas (clean and recycle) and remove furnace from pressure vessel. Remove components from furnace.



Cold isostatic pressing (CIP)

Powder is sealed in a flexible mould (or 'bag'), of polyurethane for example, and is then subjected to a uniform hydrostatic pressure.

CYCLE TIME

HIP very long. CIP shorter but sintering still time consuming.

QUALITY

Products have relatively low porosity. Distortion possible in high aspect ratio components.

FLEXIBILITY

Good as tooling (containers) relatively inexpensive. Machinery very flexible.

MATERIALS UTILIZATION

Near net shape process. 100% material utilization.

OPERATING COST

CIP relatively expensive. Containers and machinery for HIP extremely expensive.

Sintering

A thermal treatment for bonding particles together into a coherent, predominantly solid structure via mass transport events that occur largely at the atomic level. The bonding leads to improved strength and lower the system energy

Variants

- Solid-State Sintering
- Liquid Phase Sintering

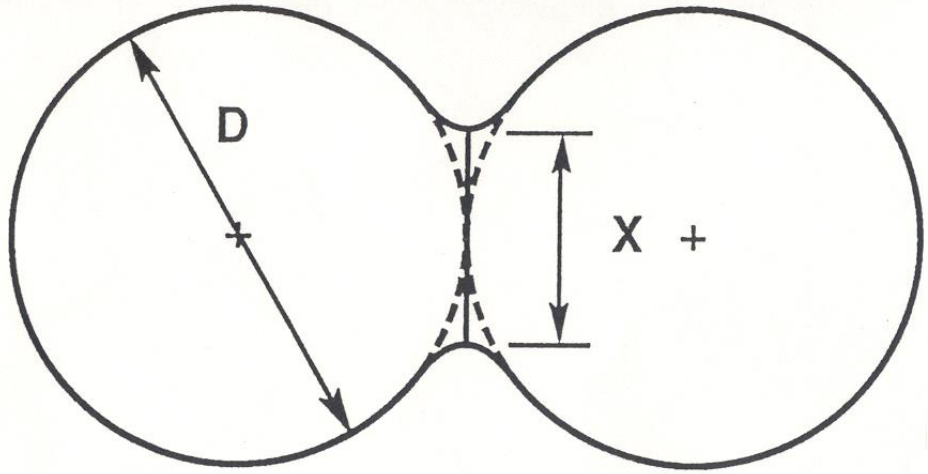
> persistent liquid phase sintering

tungsten heavy alloys (ordnance application as penetrator); cemented carbides (cutting tool application)

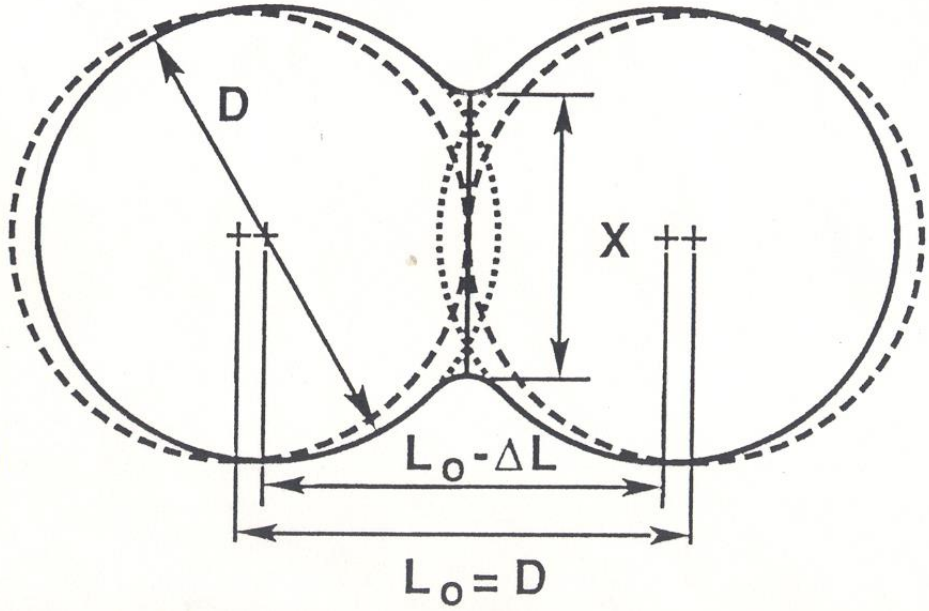
> transient liquid phase sintering

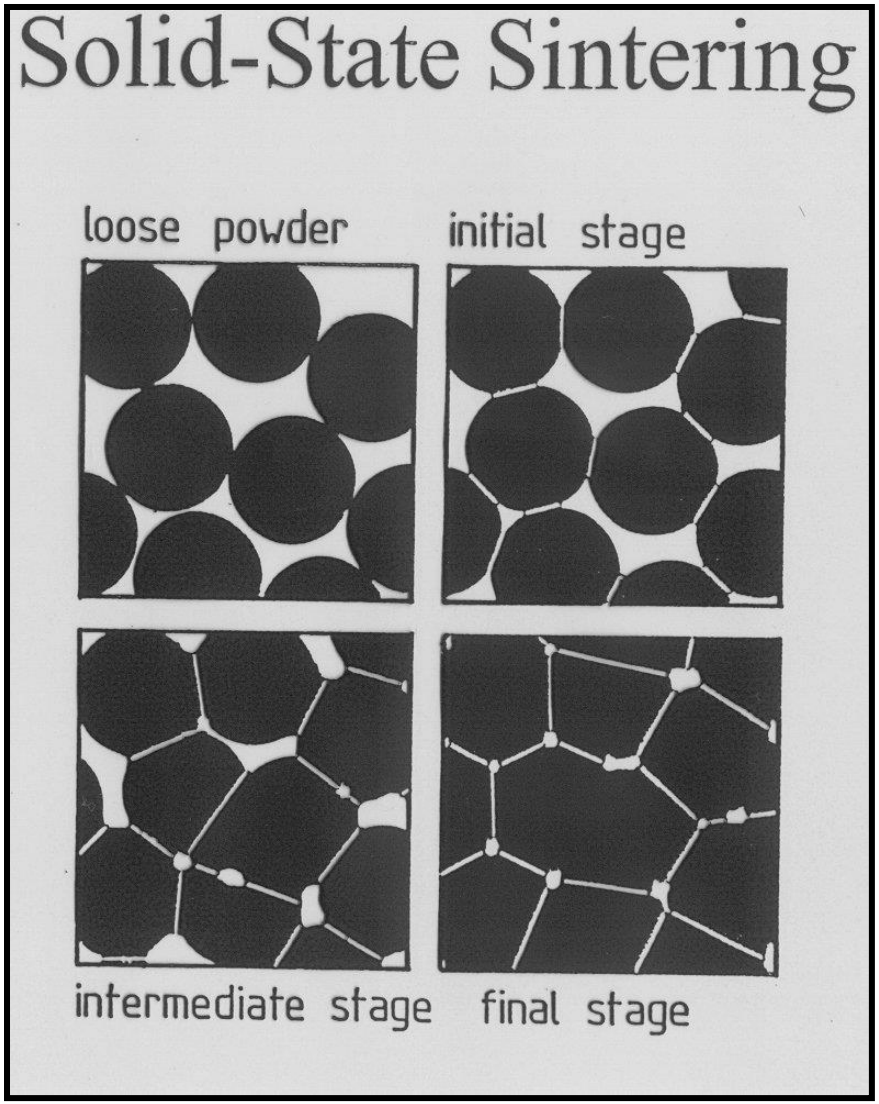
Cu-Sn bronze (oil-impregnated bronze bearings)

Before Sintering
point contact



After Sintering
Formation of inter-particle bonds
Neck
center-to-center distance between the two particles shown in fig. reduces





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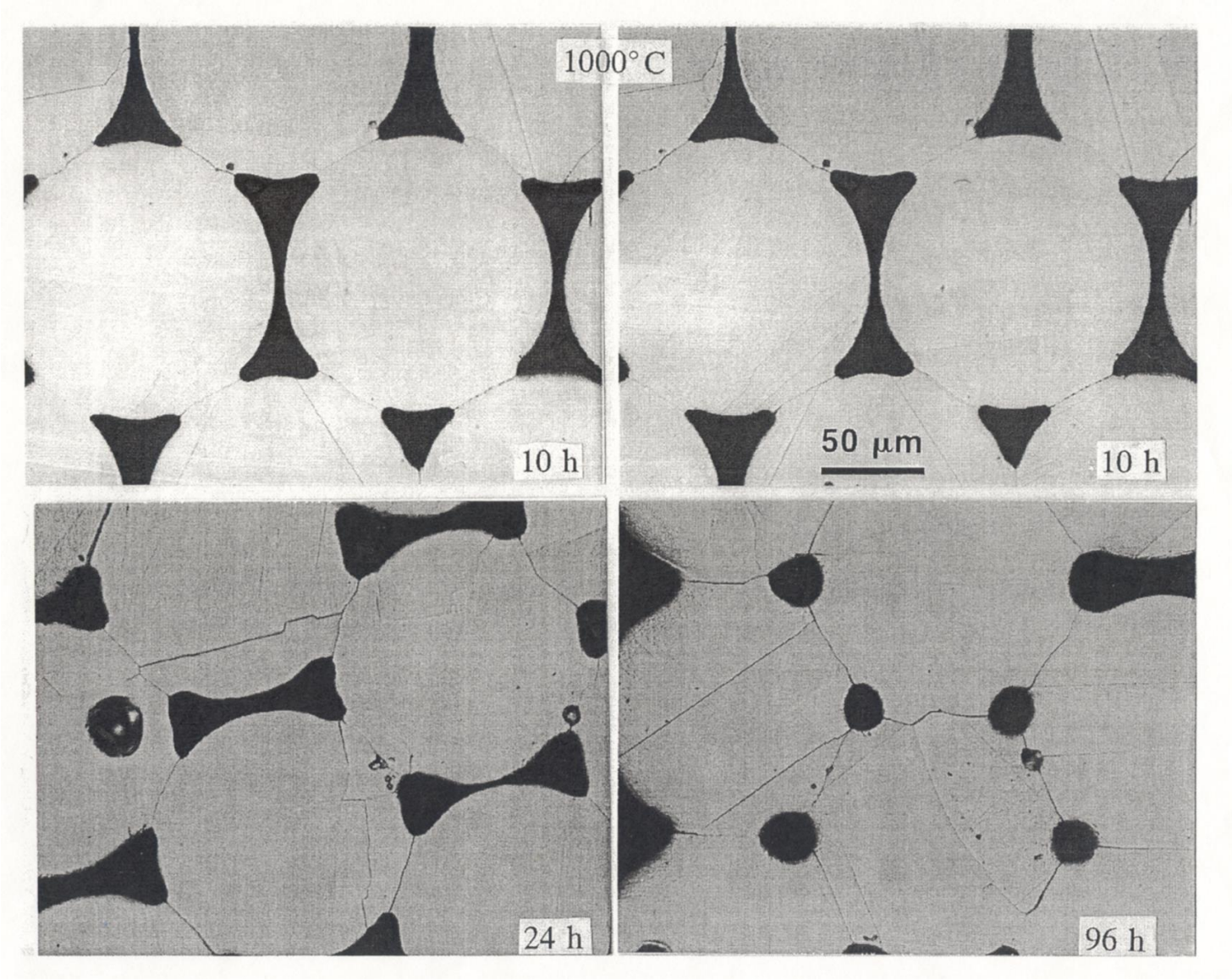
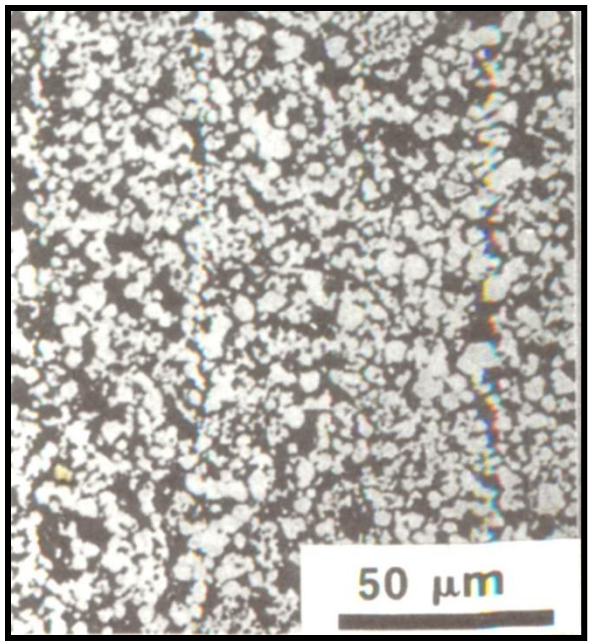
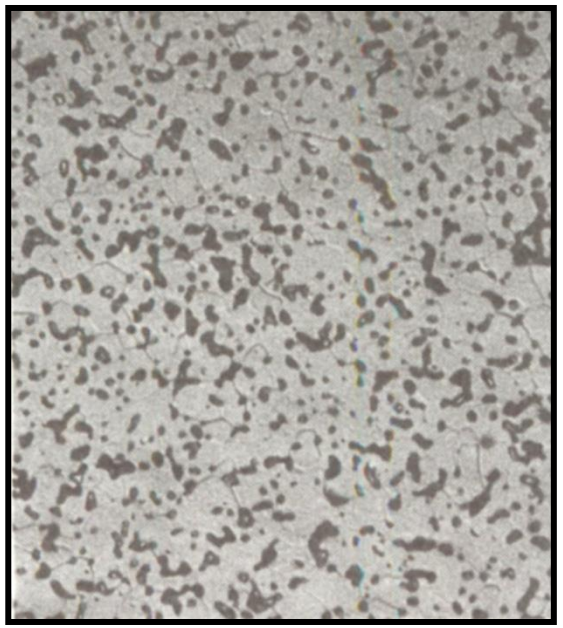
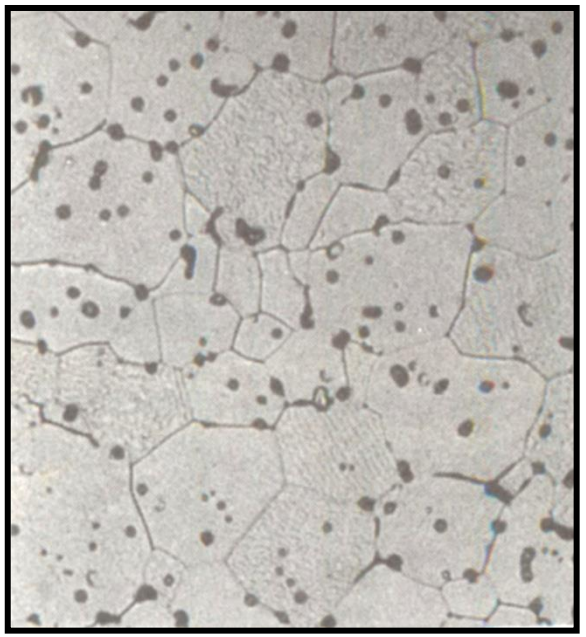


Solid-State Sintering Stages





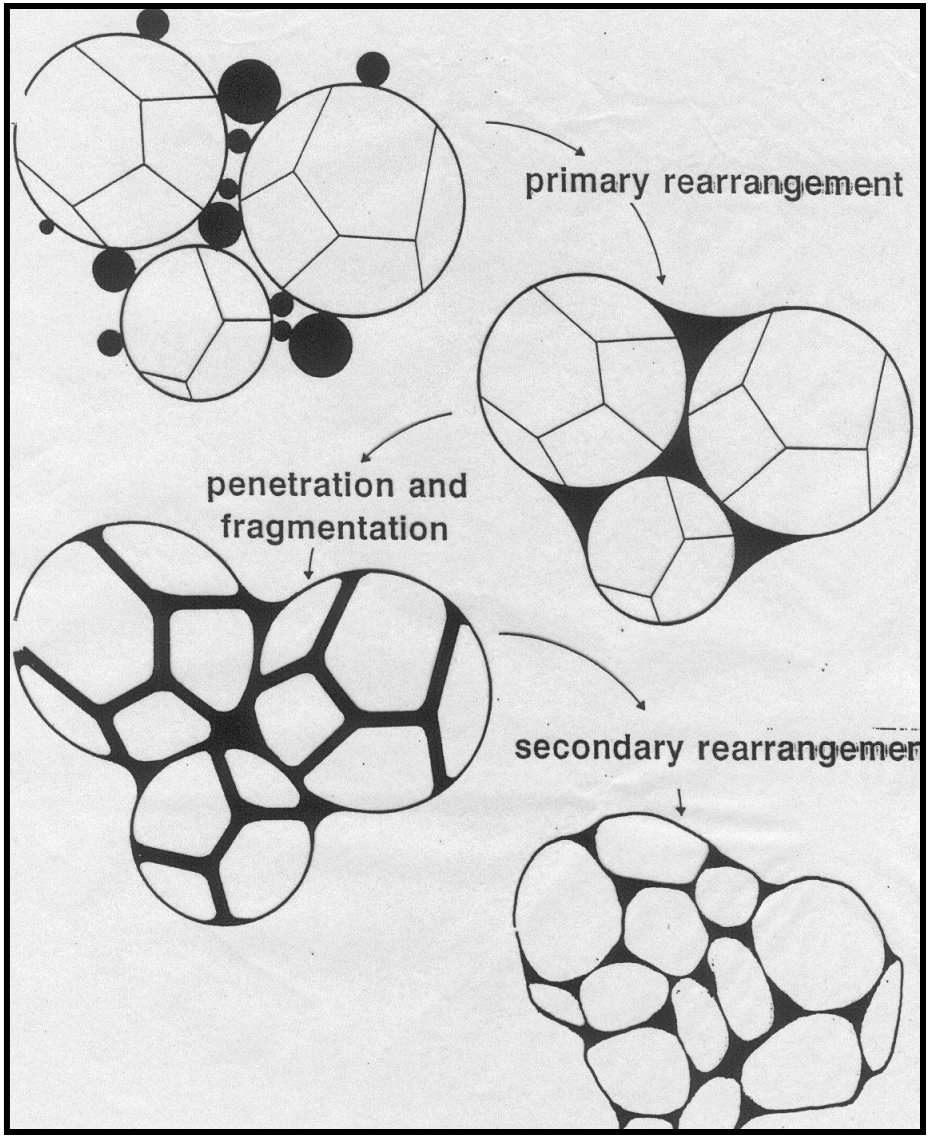


initial **intermediate** **final**

- W powder size: 5 µm
- green density: 58% theoretical
- sintering temp.: 1750°C

Note that despite sintering at such high temperature, there is still some residual porosity (shown as black regions)

Liquid Phase Sintering



During rearrangement densification occurs by capillary-stresses due to the presence of liquid phase

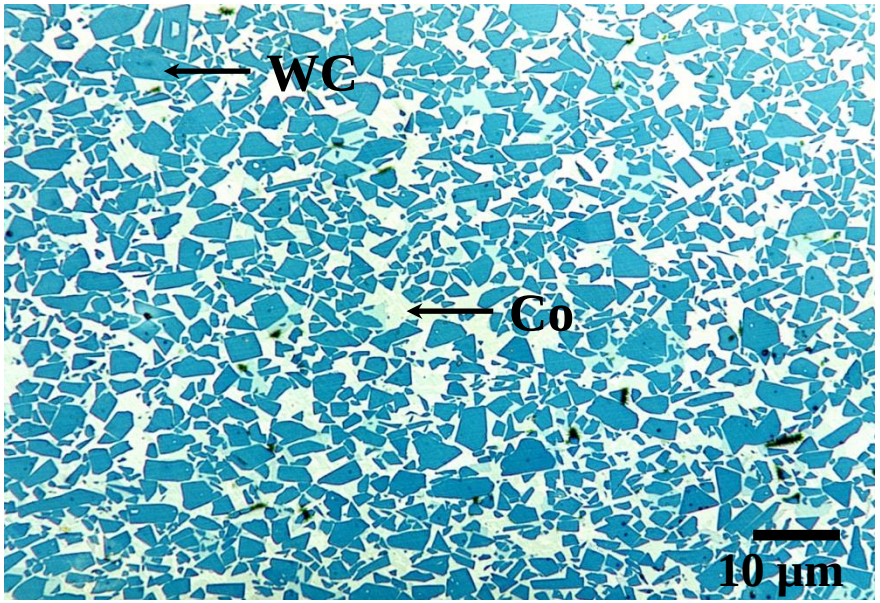
Non-Wetting System

- **Al-40Sn**
- **550°C, 1h in N_2**

Sn (melt) does not wet Al and hence ‘sweats’ out

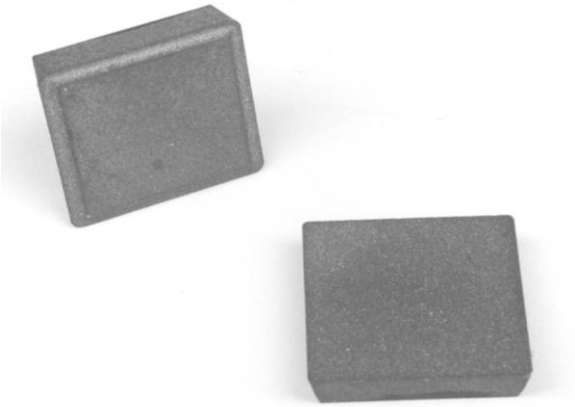
Illustration

WC-Co Alloys (Cemented Carbides)



1350°C, 60 min

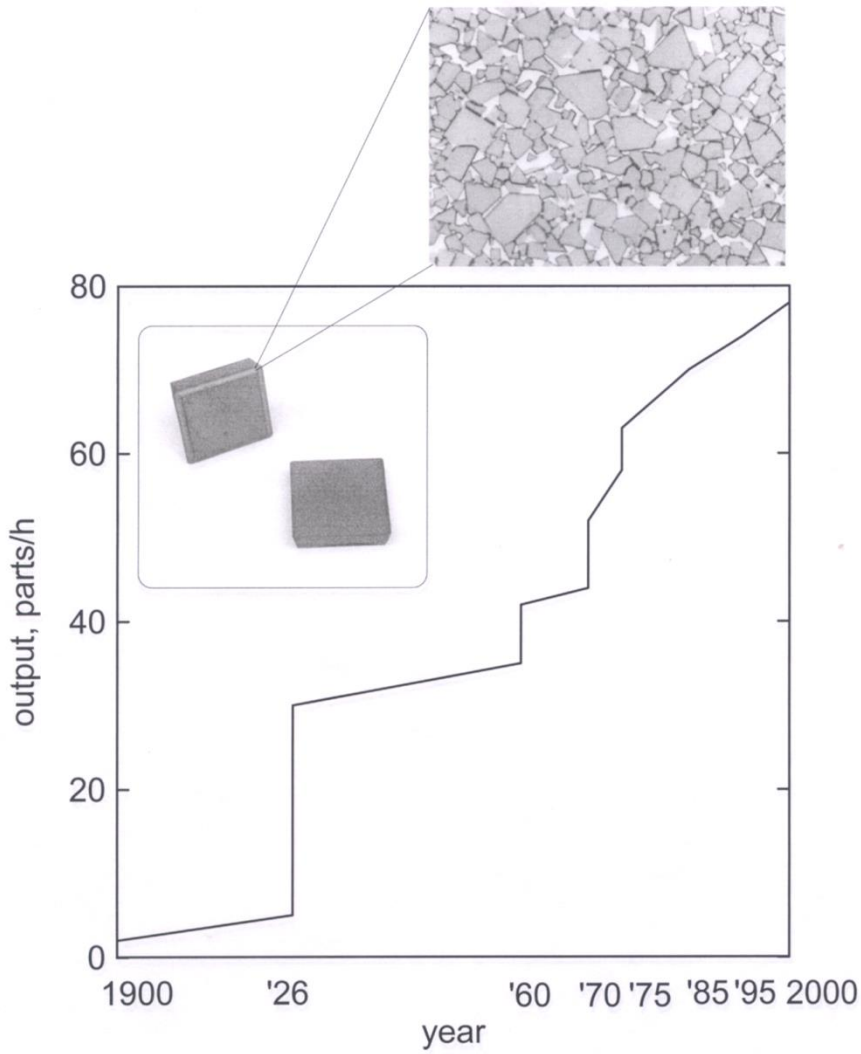
photo courtesy: K. Sivaraman



tool bits

drill bits

Cutting tool inserts



Earlier, high speed steel (HSS) which was manufactured by casting route was used for cutting applications. Such steels are called cutting tool steels. However, they cannot be used by cutting at high speeds wherein the temperature can exceed 600°C. For still higher cutting output, hardmetals or cemented carbides [WC-(6-10 wt.%)Co] is used. Such alloys are consolidated by liquid phase sintering.