THE WOLFSON CENTRE

for Bulk Solids Handling Technology

POWDER FLOW in the AM PROCESS:

Understanding its impact and potential problems

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Wolfson Interests in Powder AM

Technical areas

- Powder quality
  - Oxidation
  - Segregation
  - Agglomeration
  - Recycling
  - Cross-contamination
- Powder flow
  - Handling & delivery
  - Spreading
- Process efficiency
  - Conveying, storage, feeding
  - Separation, grading, filtration
  - Delivery rate and energy
  - Self-optimisation (Ind. 4.0)
- Powder engineering
  - Controlling powder behaviour

Activity streams

- Consultancy
  - Process design
  - Troubleshooting
- Research
  - Fundamental
  - Applied
- Education
  - Short courses for industry
  - Outreach events

Powders in AM: Key factors

- Powder manufacture and properties
- Requirements on the powder for consistent product quality
- Requirements on the deposition system for consistent product quality
- Outline of powder recycle and quality issues

FUNDAMENTAL REQUIREMENTS to achieve good product from particles

Powder going into component must, throughout the build operation, have

- **Consistent processing properties**
  - **Ink penetration, retention and colour**
  - **Water penetration and retention**
  - **Heating**
  - **Sintering properties**

FUNDAMENTAL REQUIREMENTS to achieve good product from particles

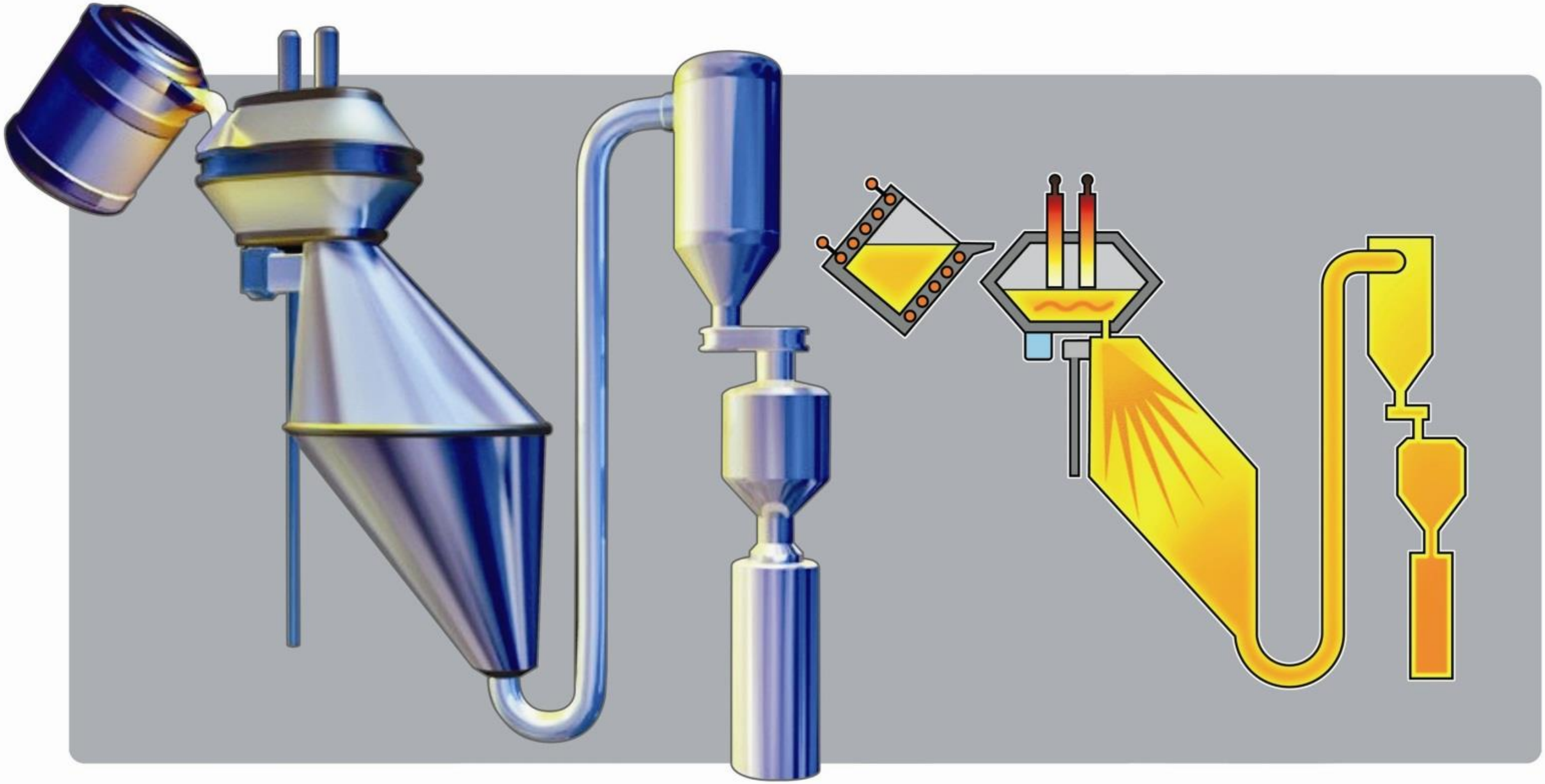
To have consistent processing properties, the powder going into component must have

- **Consistent flow properties**
- **Consistent bulk density**
- **Consistent blend of species if multi-component**
- **Consistent particle size (median and distribution)**
- **Consistent particle shape**
- **Consistent flow rate**
- **Consistent mechanical and chemical properties**

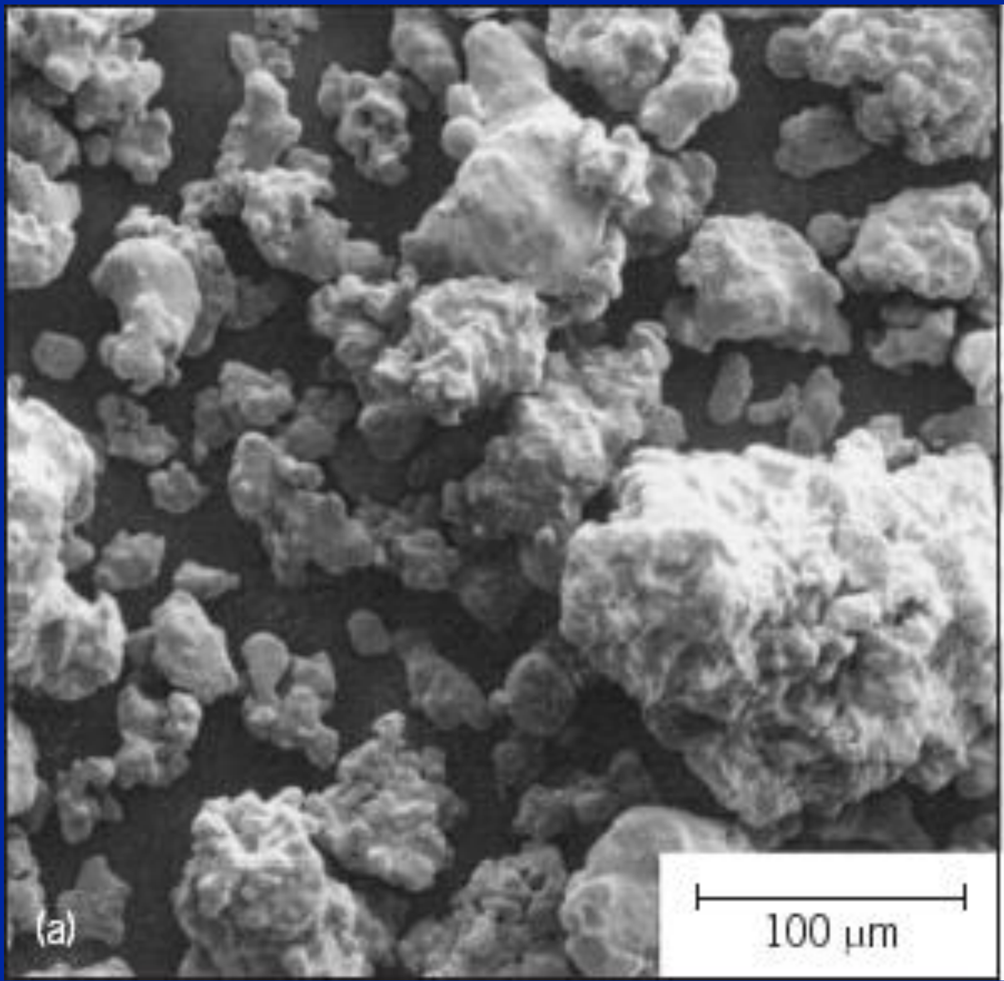
Powder Manufacture

Metal powders – melted, atomised and cooled

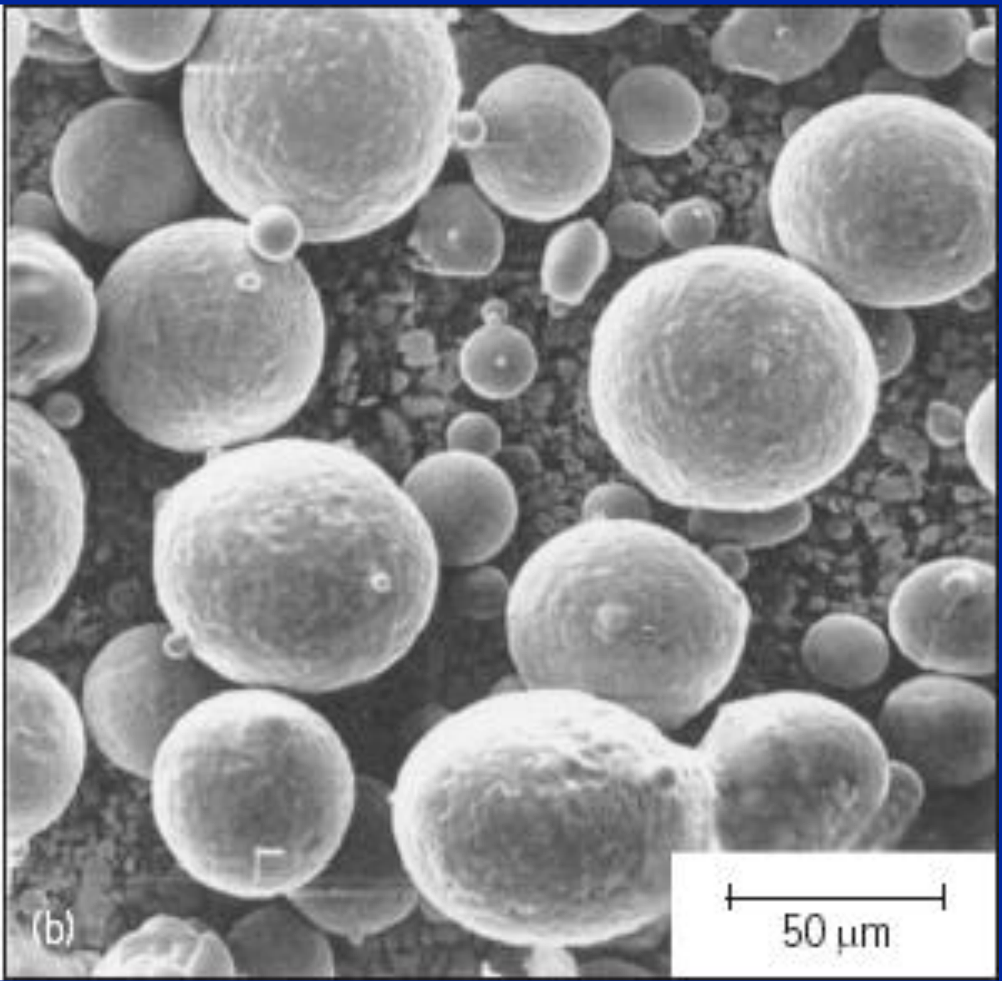
Then heat treated



Water Atomised

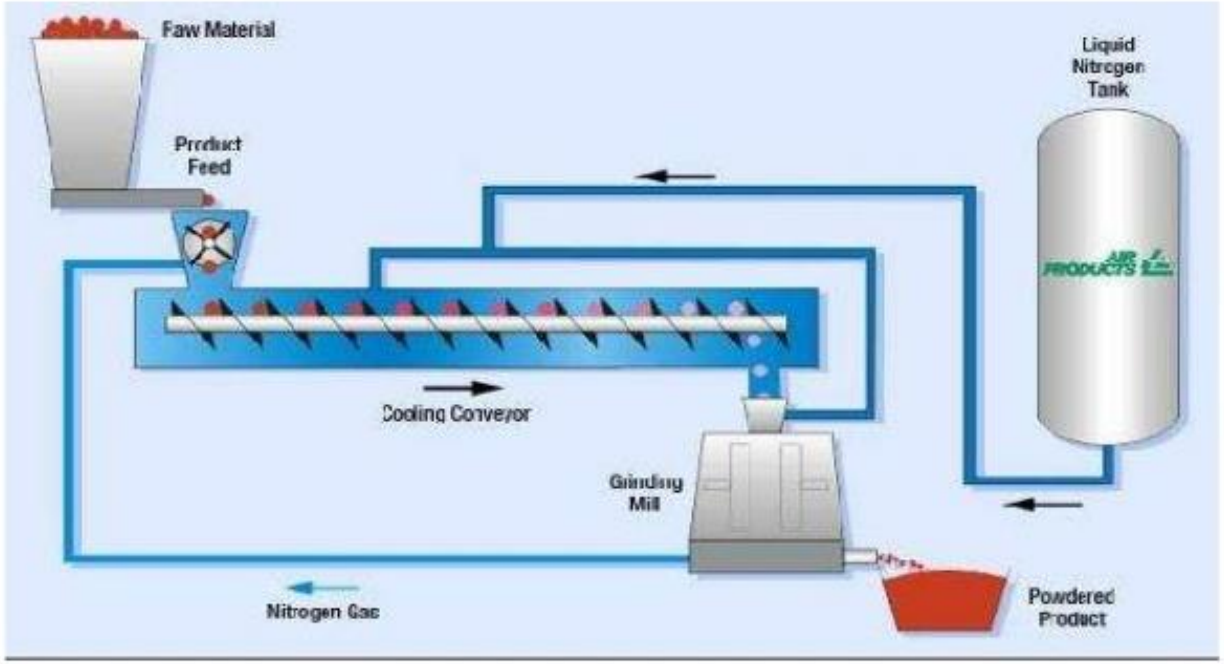


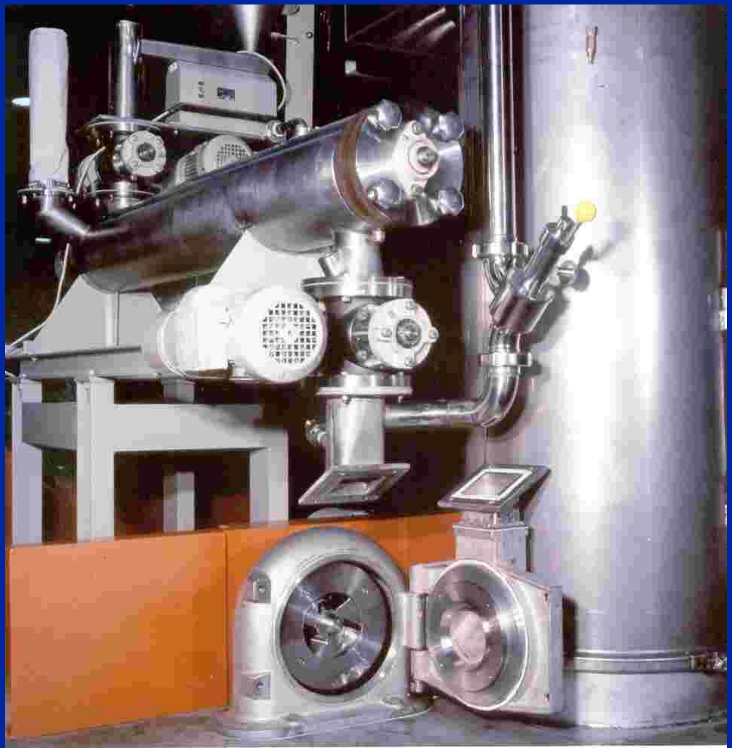
Gas Atomised



- Cryogenic grinding – to make the material brittle enough to crush, and prevent thermal degradation
- May be followed by heat treatment, spheronisation to control particle shape
- Usually sieving to control size grading

Making plastic powder

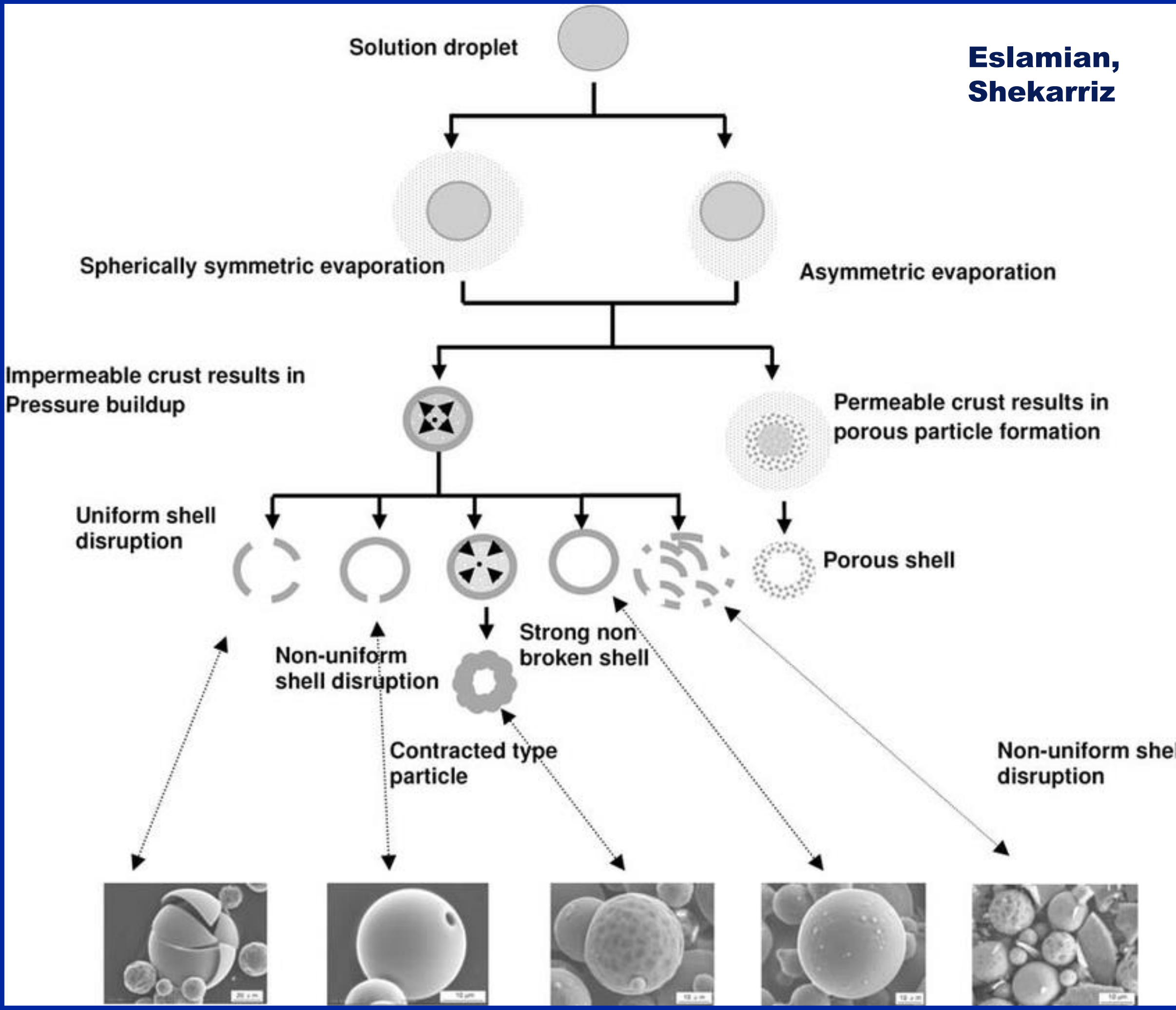




Spray dried ceramic powder

- Often quite spherical
- Often hollow
  - Low density
  - Compressible
  - High shrinkage
- Wide size distribution
  - Often sieved to control PSD

Many different possible particle structures, sizes and densities according to spray drying conditions!



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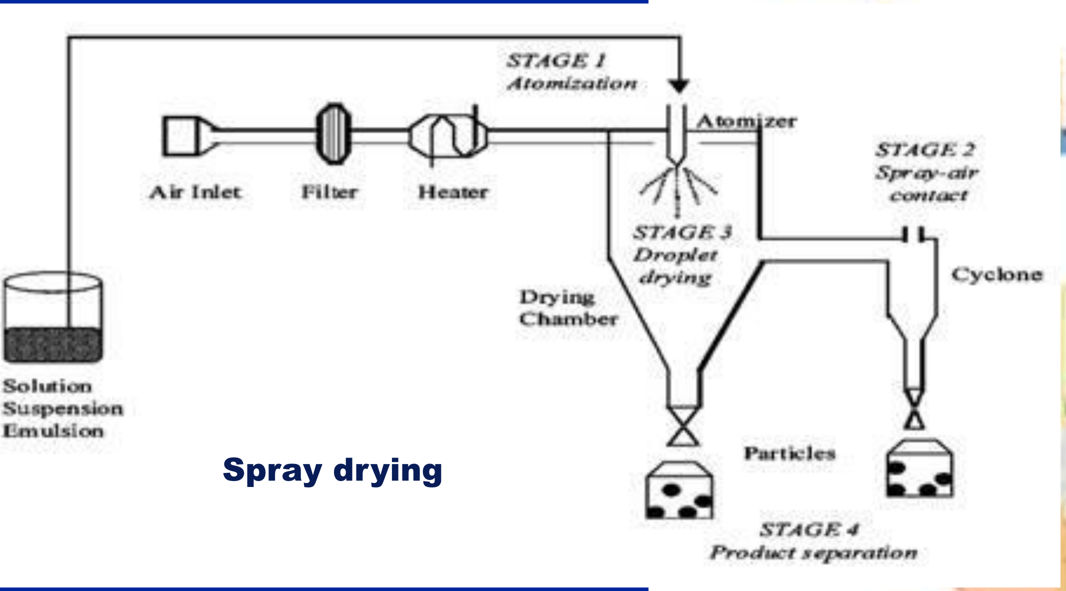
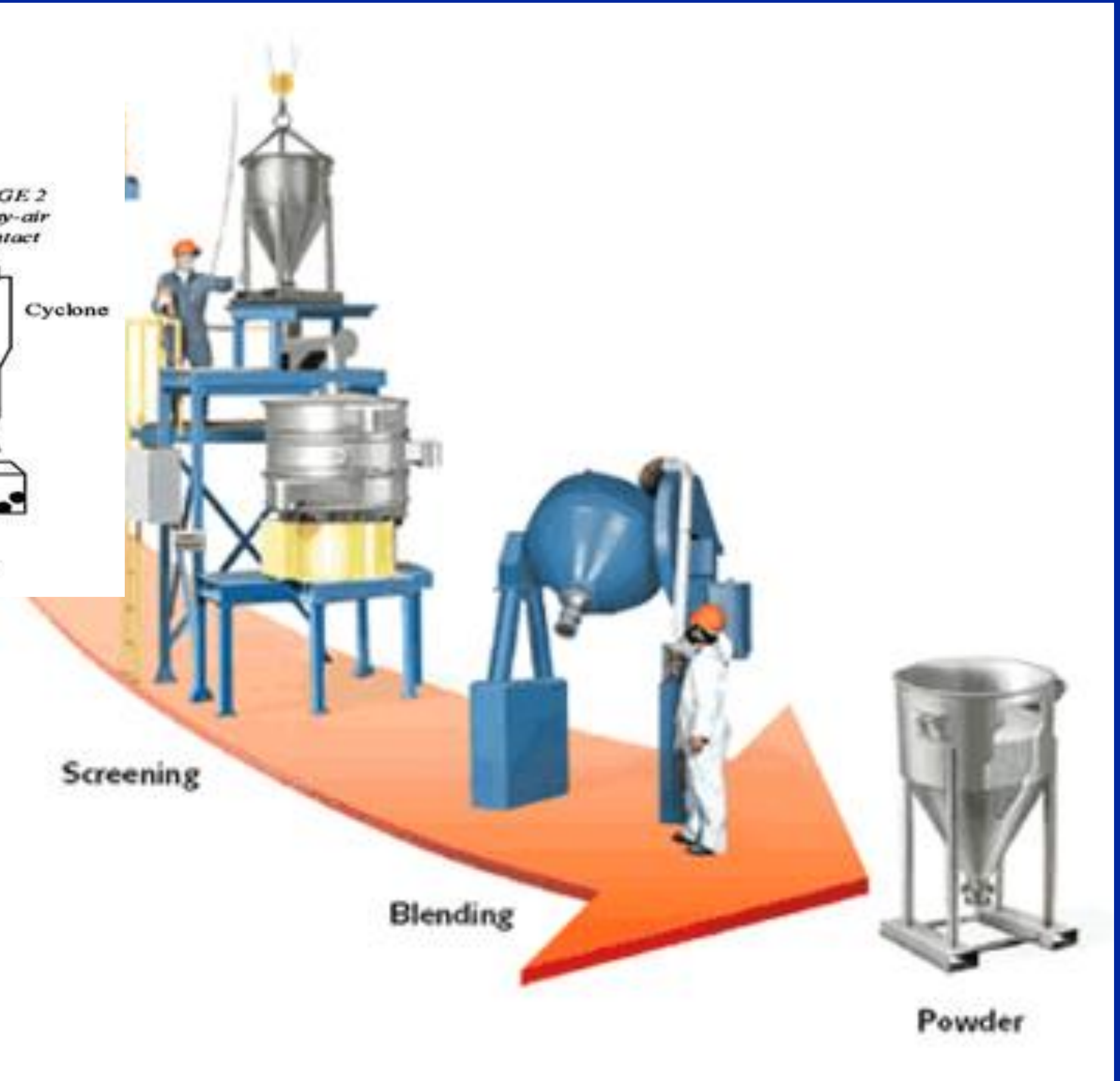
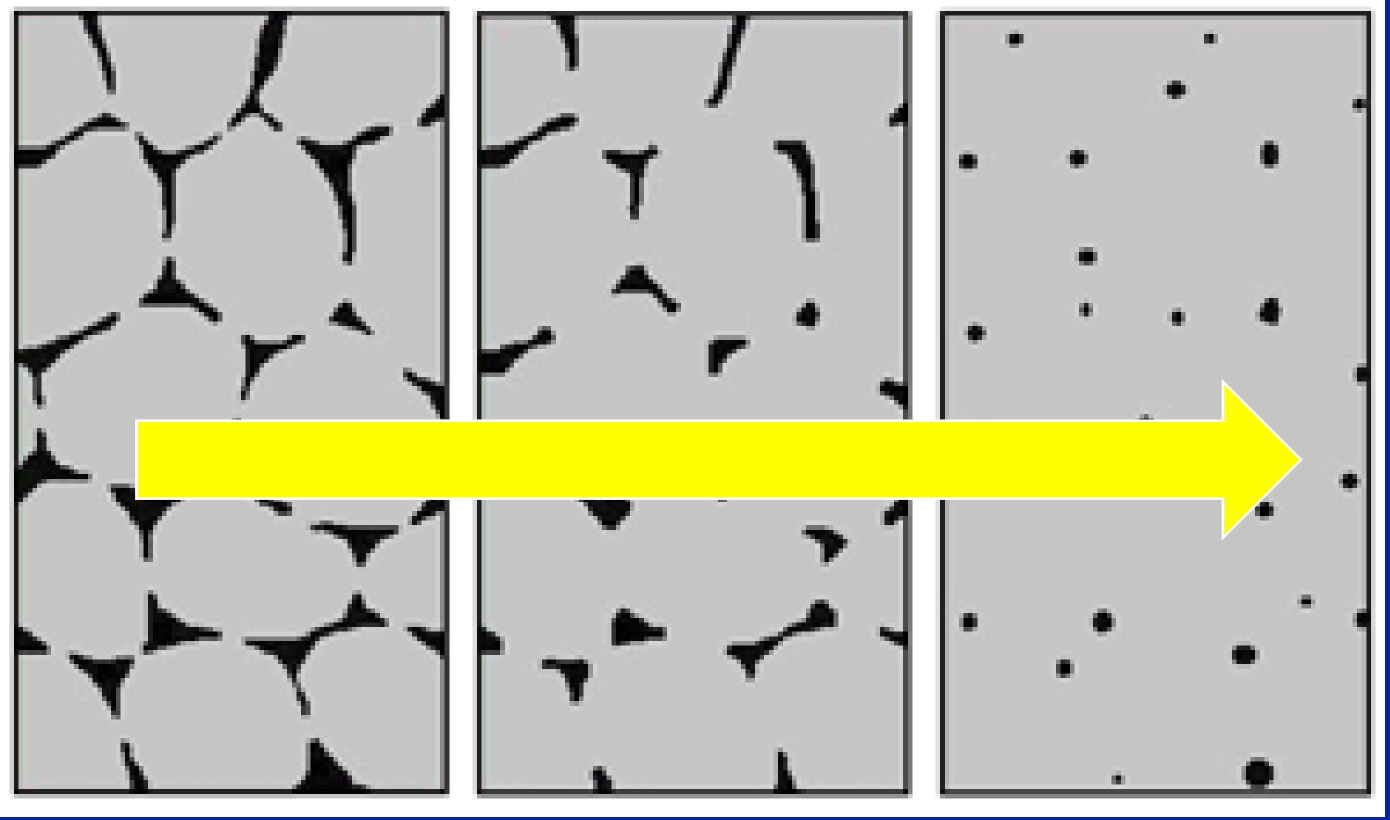
Powder preparation



Spray drying



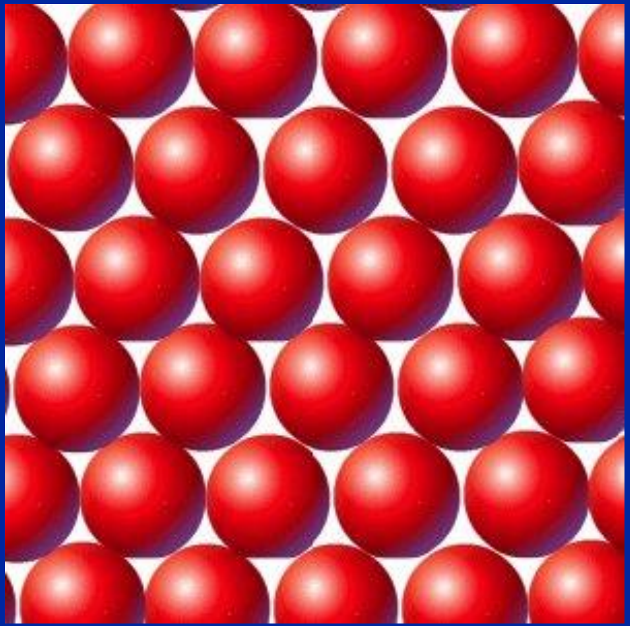


Sintering

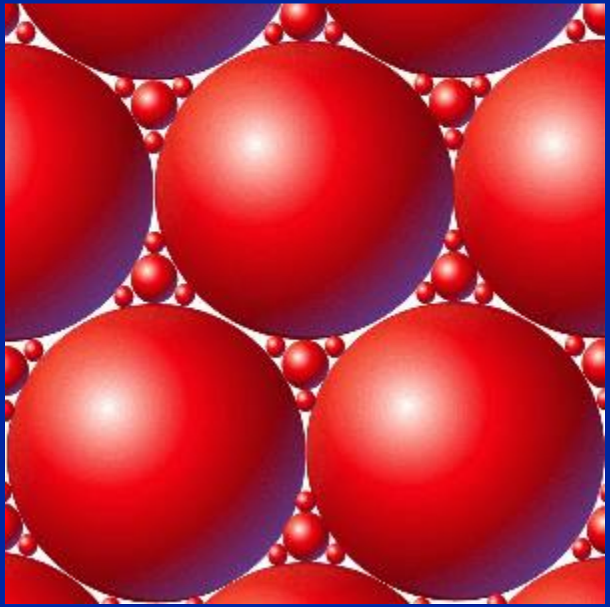
- The gaps between the particles are partially eliminated
- The particles themselves can shrink if internal voidage
- So the overall structure shrinks
- Effect of PACKING and FINISHED DENSITY
- Which way does it shrink and how much?

Narrow size distribution

- Lower packing density
- Higher voidage (porosity)
- More shrinkage in sintering
- Lower sintered strength
- Less segregation



Powder packing



Broad size distribution

- Higher packing density
- Lower voidage (porosity)
- Less shrinkage in sintering
- Higher sintered strength
- More segregation

Trade-off in size distribution

Wide distribution

- More segregation
  - More variation in all properties
- More fines
  - Poorer flow – hang-ups etc, harder to spread a consistent layer
  - More stress needed to compact
  - More compressible
  - More fugitive dust
- More surface area
  - More oxidation

Narrow distribution

- Less of the problems on the left
- More consistent in all regards
- Harder to make
- More expensive
- More shrinkage

Trade-off in median size

Larger median size

- Thicker layer needed
- Coarser part finish
- Better flow properties
  - Easier flow – fewer hang-ups
  - Easier to spread a consistent layer
  - Less stress needed to compact
  - Less compressible
  - Easier to sieve
- More segregation
  - More variation in all properties
  - Less fugitive dust
- Less surface area
  - Less oxidation

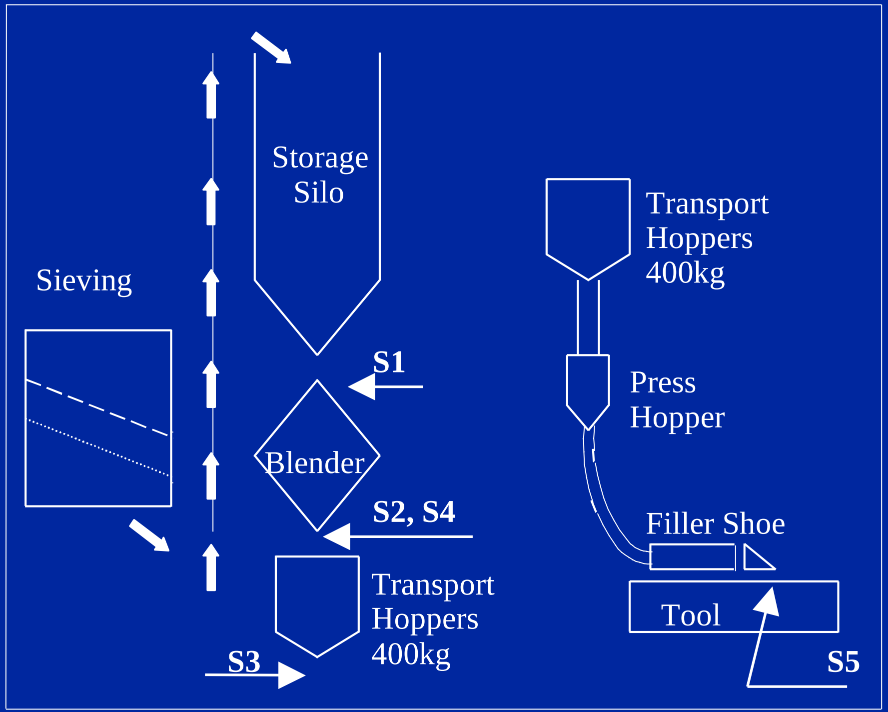
Smaller median size

- Can be spread thinner
- Better finish
- Poorer flow properties
  - Poorer flow – more hang-ups
  - Harder to spread a consistent layer
  - More stress needed to compact
  - More compressible
  - Harder to sieve
- Less segregation
  - Less variation in all properties
  - More fugitive dust
- More surface area
  - More oxidation

Segregation in powder handling

- **A case study from a ceramic powder handling process**

- **Alumina powder spray dried, used in press-and-sinter manufacture**



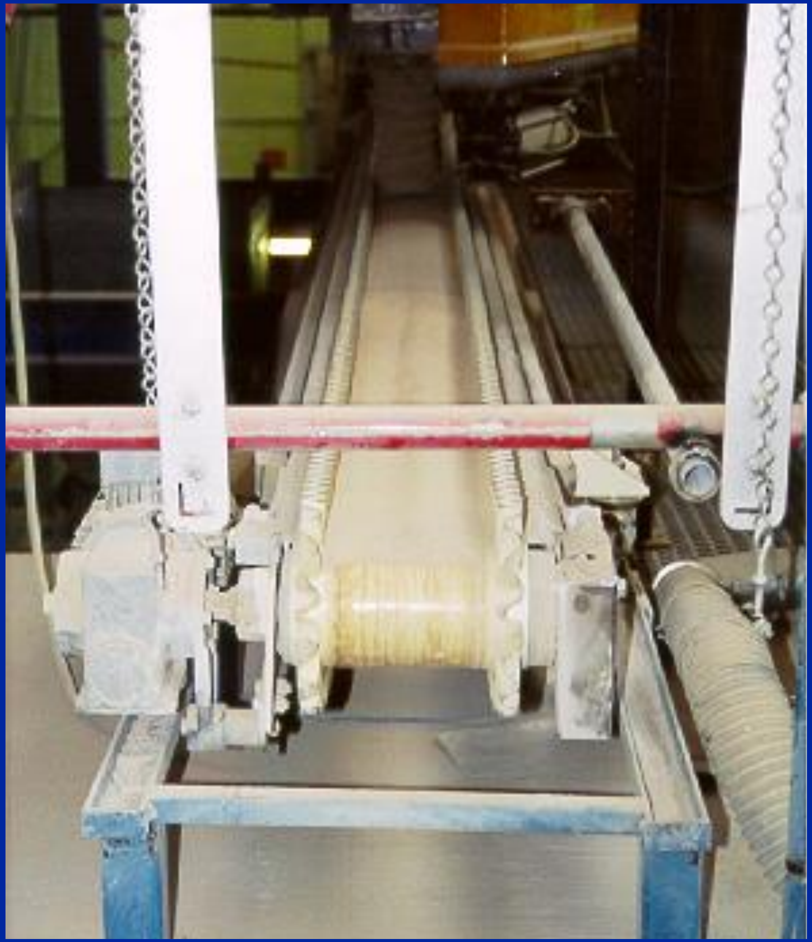
CASE STUDY (I)

- **Goal:**
  - **Investigate segregation arising from transport hoppers**

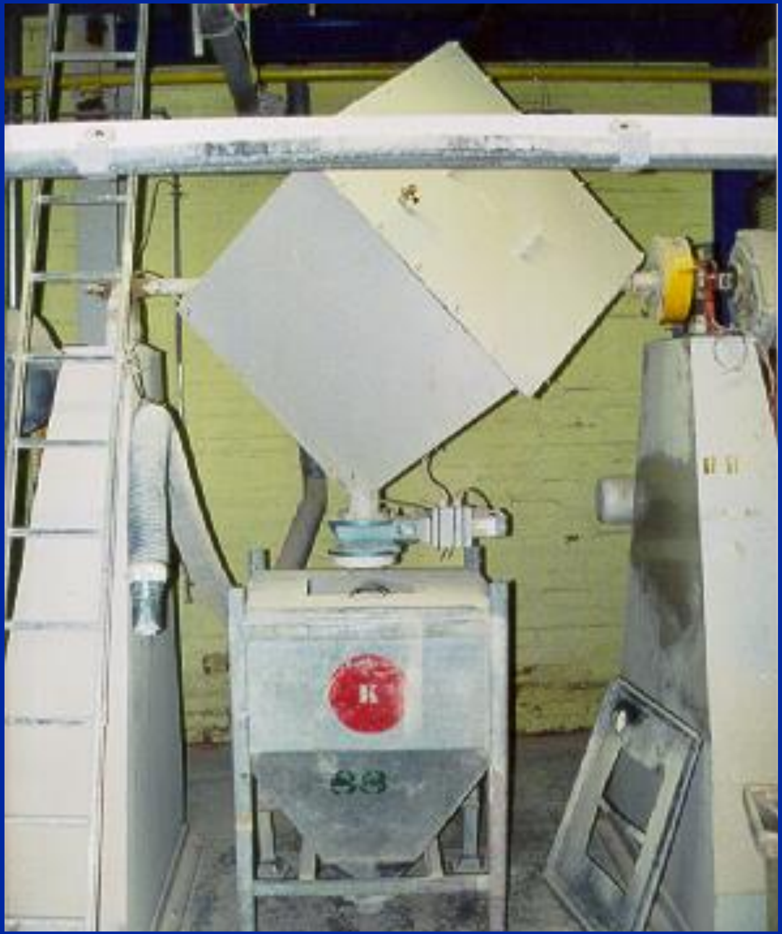
CASE STUDY (II)

- **Sampling points:**

Feed to blender



Blender outlet



CASE STUDY (IV)

- **Sampling points / continued:**

Hopper outlet

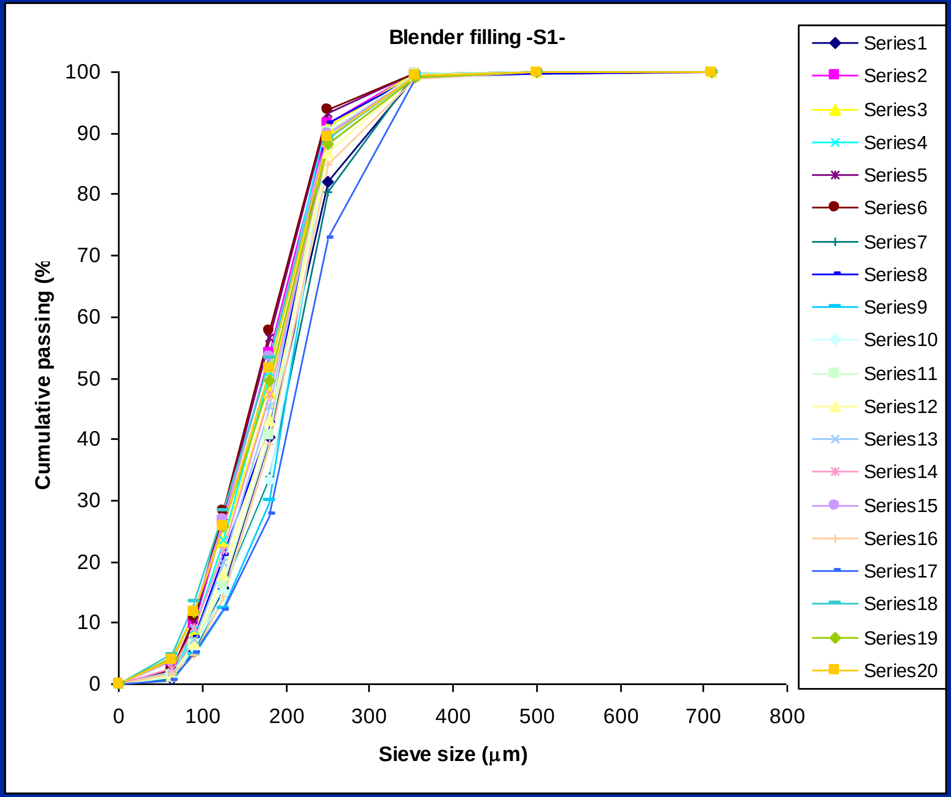
(in free discharge)

Press shoe

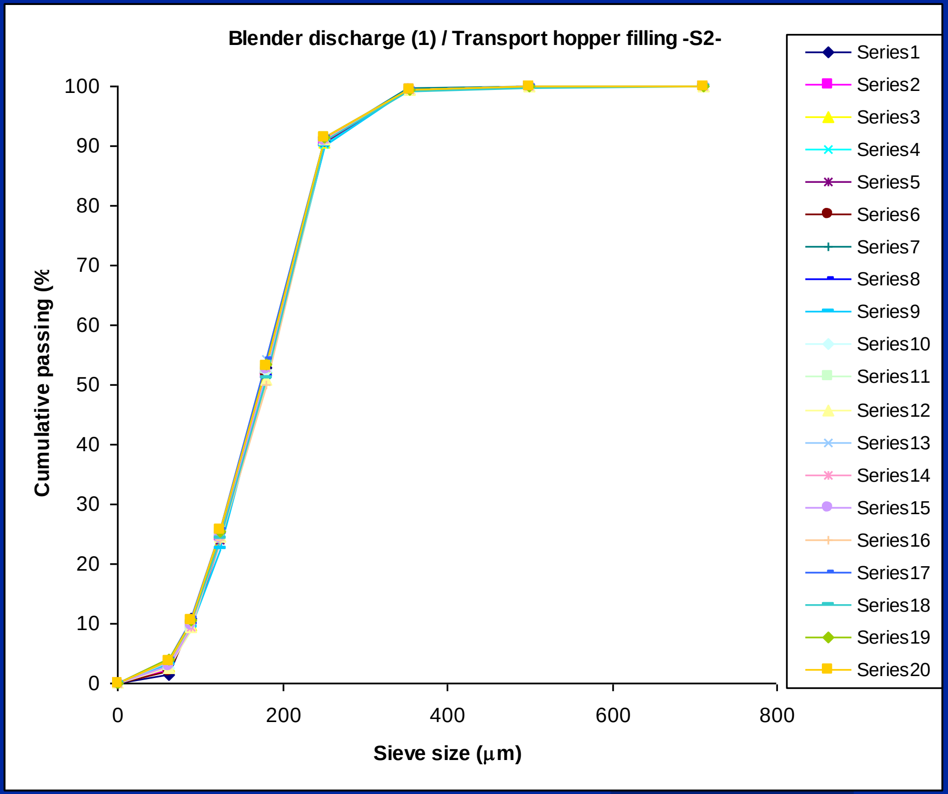
CASE STUDY (V)

- **Results: particle size distributions (cumulative)**

Blender in-feed



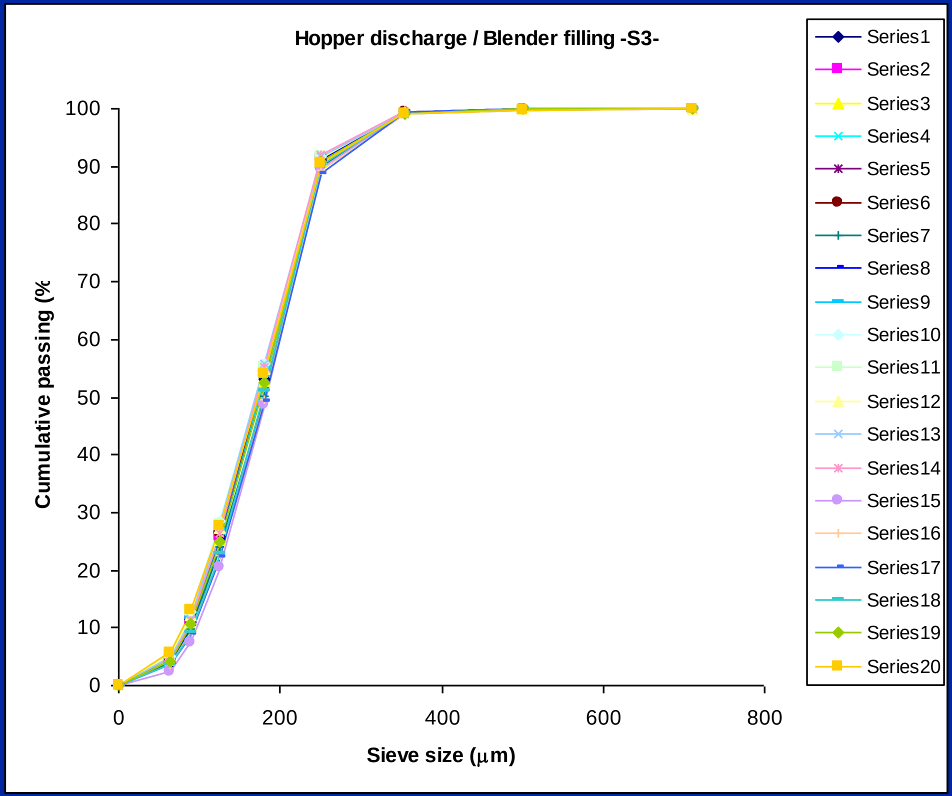
Blender discharge (hopper in-feed)

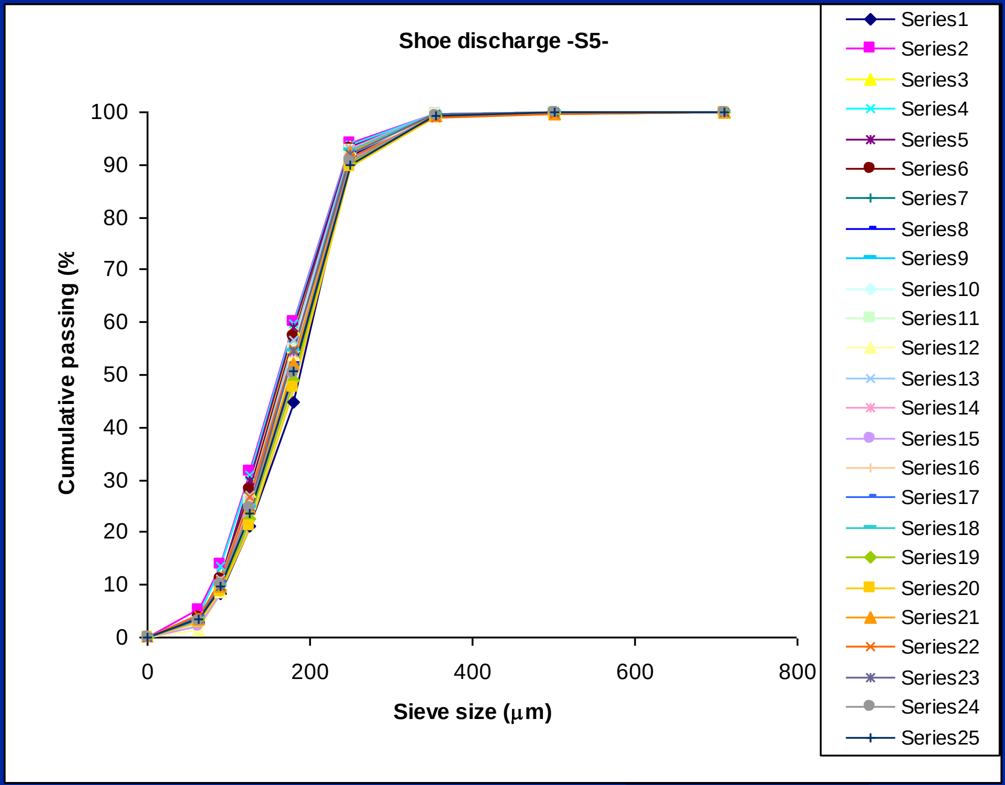


CASE STUDY (VI)

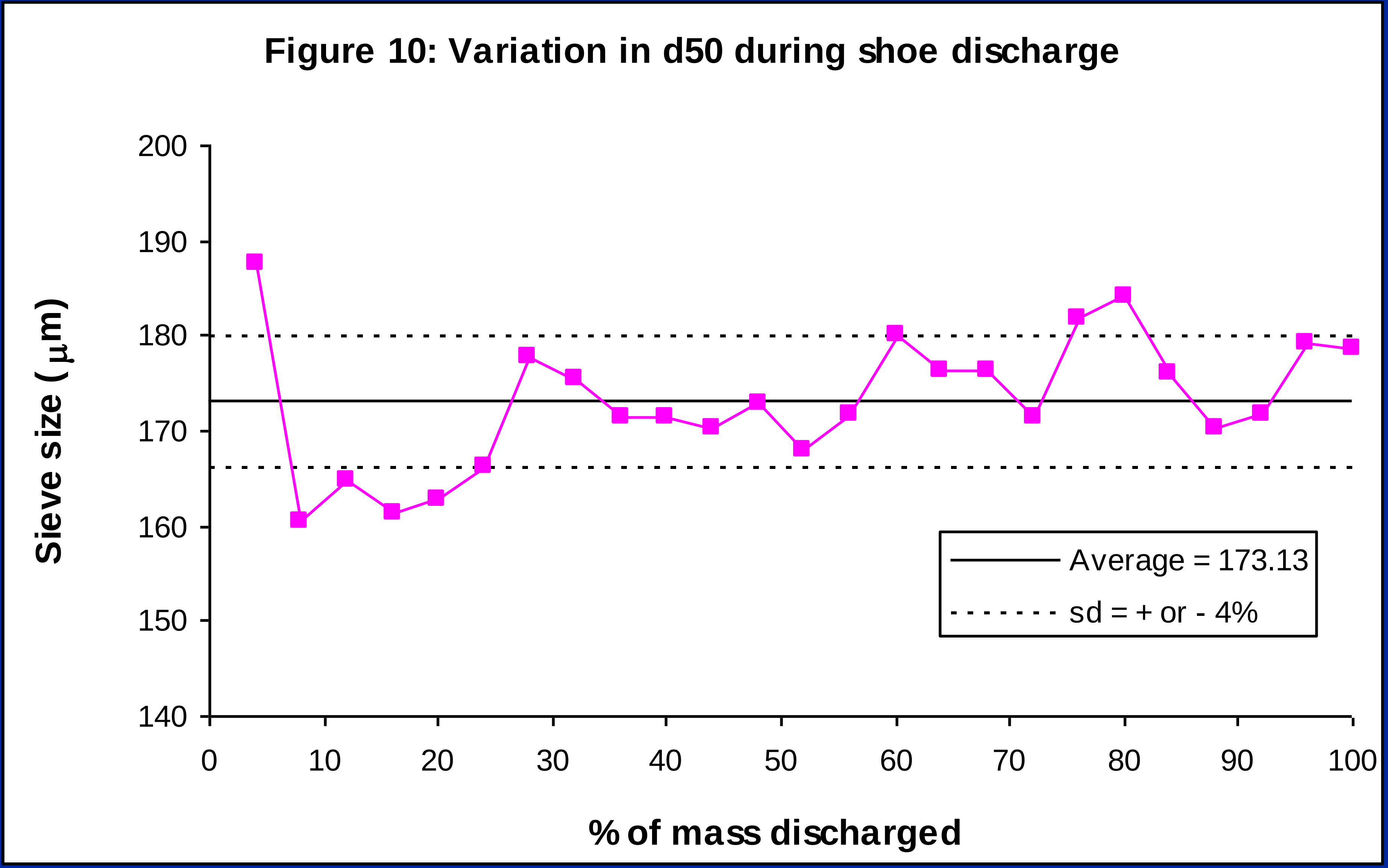
- **Results: particle size distributions (cumulative)**

Hopper in free discharge / Press shoe





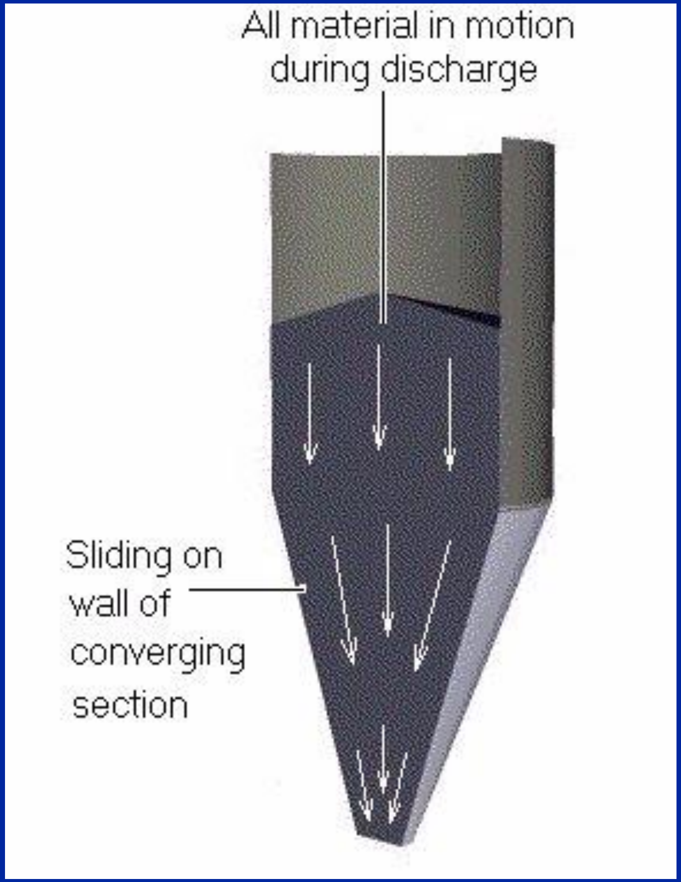
CASE STUDY (VII)



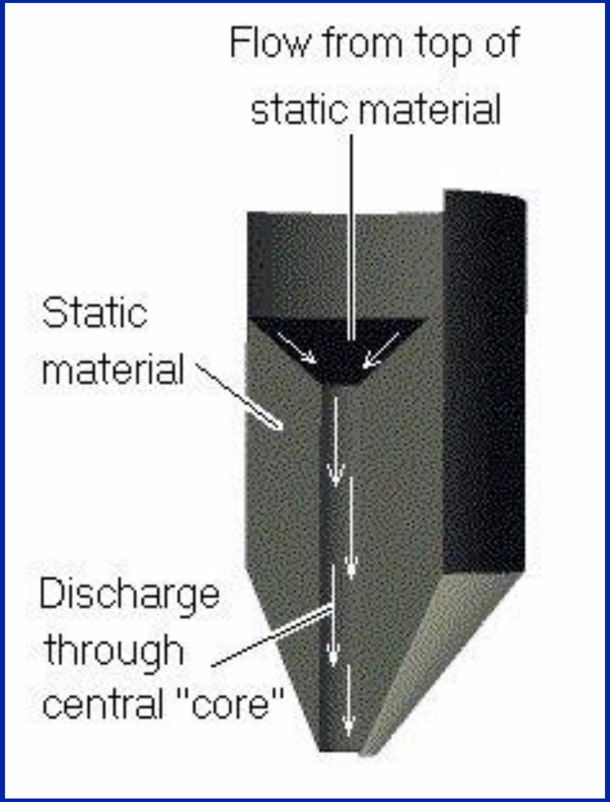
CASE STUDY (VIII): Bulk density effect

- Significant change in bulk density during discharge of container
- Clear correlation between bulk density and particle size distribution
- Variation in component size after firing
- Same effect will be seen in selective sintering

FLOW PATTERNS IN FLOODED CHANNELS:
Hoppers, filling heads



- **Mass flow**
- **Core flow**



SEGREGATION IN STORAGE

- **Separation during charging**

- **Mixture:**
  20% salt : 80% mung beans

SEGREGATION IN STORAGE

- **Discharge in core flow**

  (one-third empty)

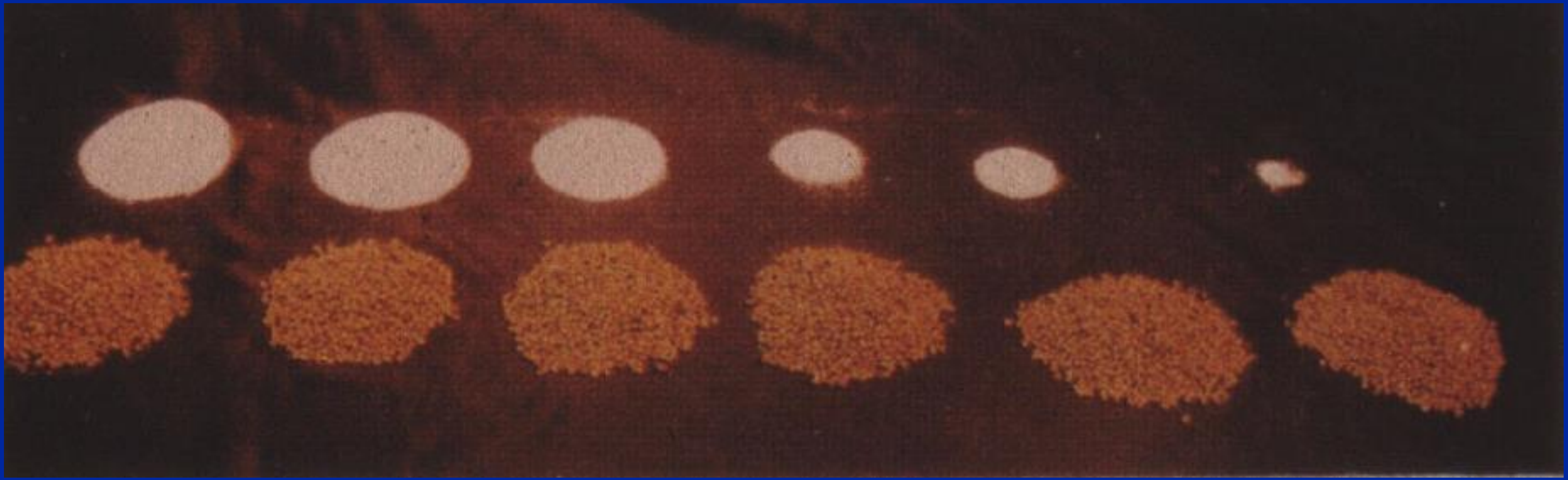
- **Mixture:**

  20% salt : 80% mung beans

SEGREGATION IN STORAGE

- **Screening results**

- **Mixture:**
  20% salt : 80% mung beans



The QPM Segregation Tester

- Equipment is portable, easy to operate, requires “small” quantities of material
- Good reproduction of plant conditions

Segregation tester results

Blend material

Set angle of repose

Form bed and divide into sections

Empty

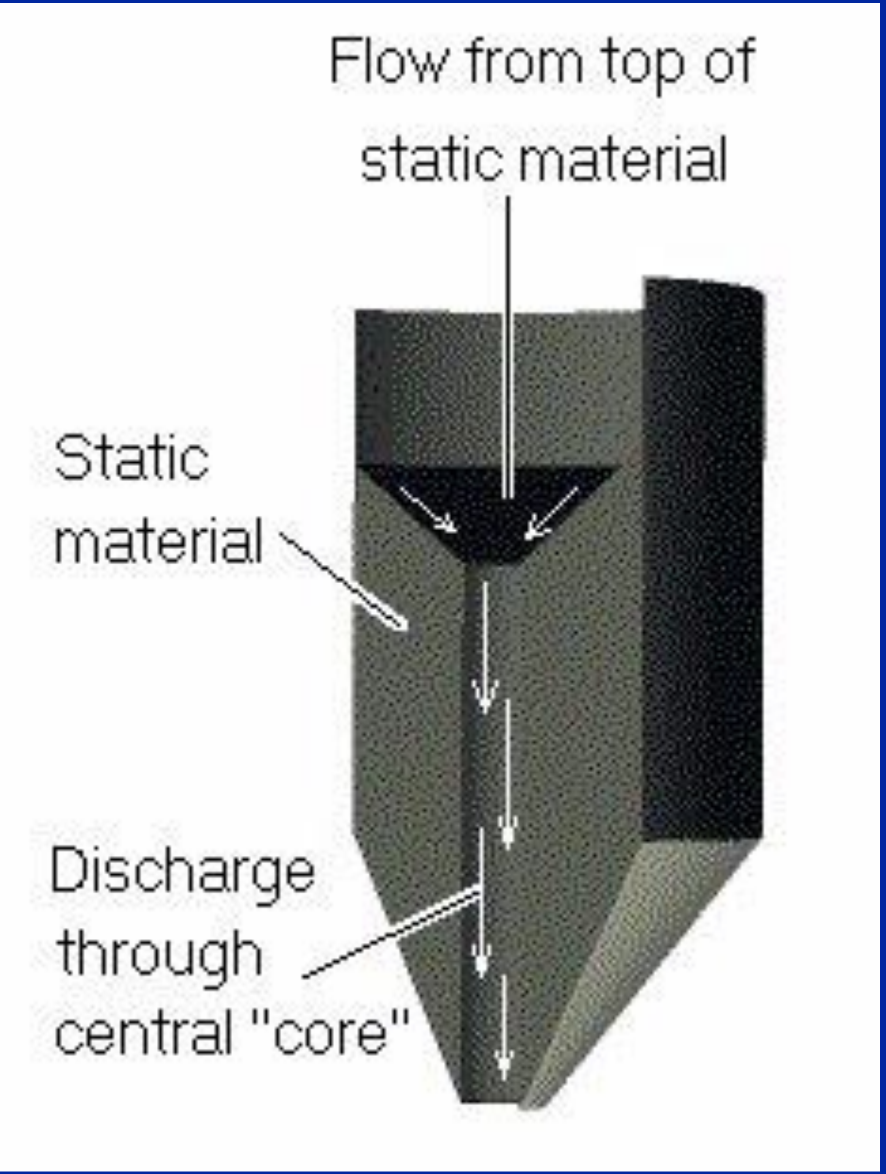
=

→ propensity

- Yields *numbers* for tendency of a material to segregate in hoppers
- Use for simple comparative purposes, or numerical predictions

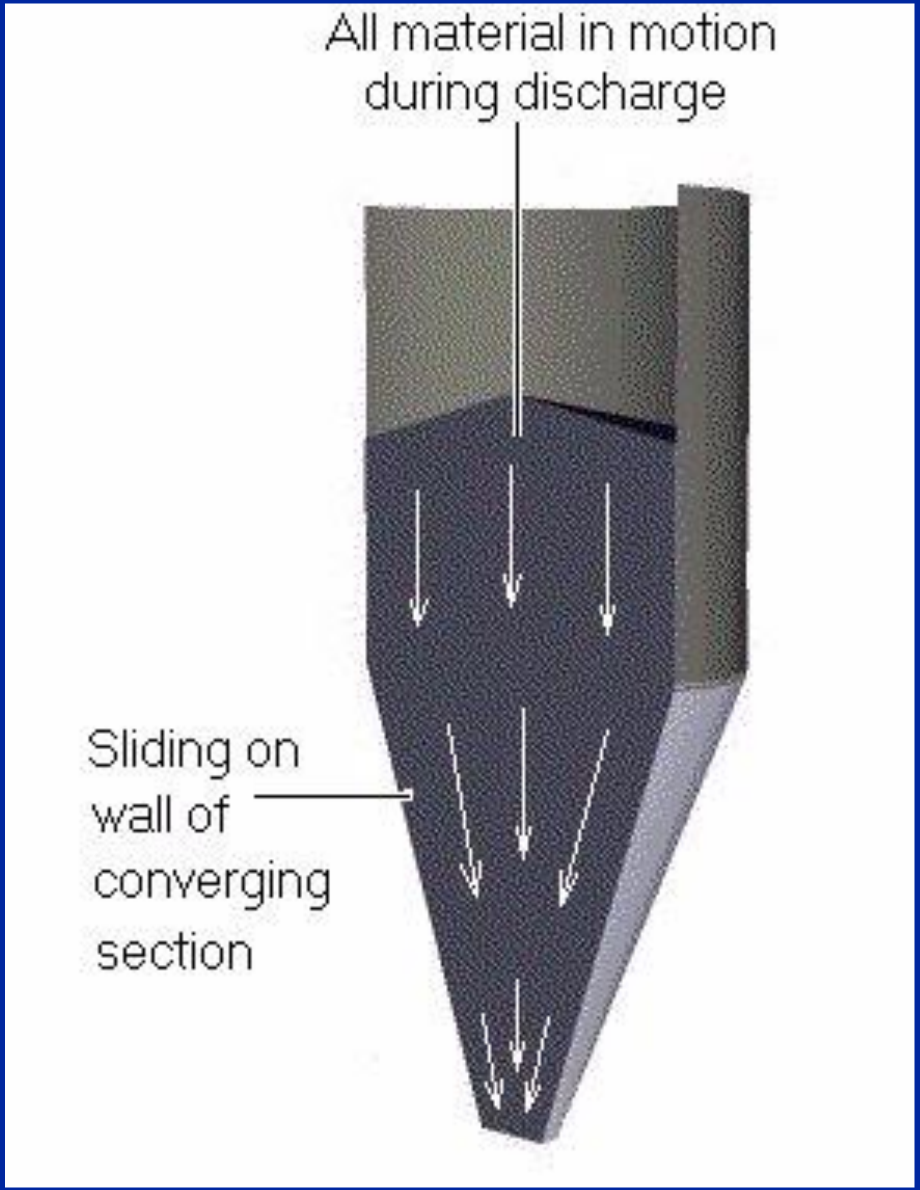
CORE FLOW

- First-in, last-out
  - Poor stock rotation
  - Static material retained
  - Spoilage & hardening of stagnant material
- Flow inconsistent: varying
  - Discharge rate
  - Bulk density
- Segregation
- Flow not well promoted
  - May "rat-hole"
  - Critical rat-hole dimension much larger than mass flow arching dimension



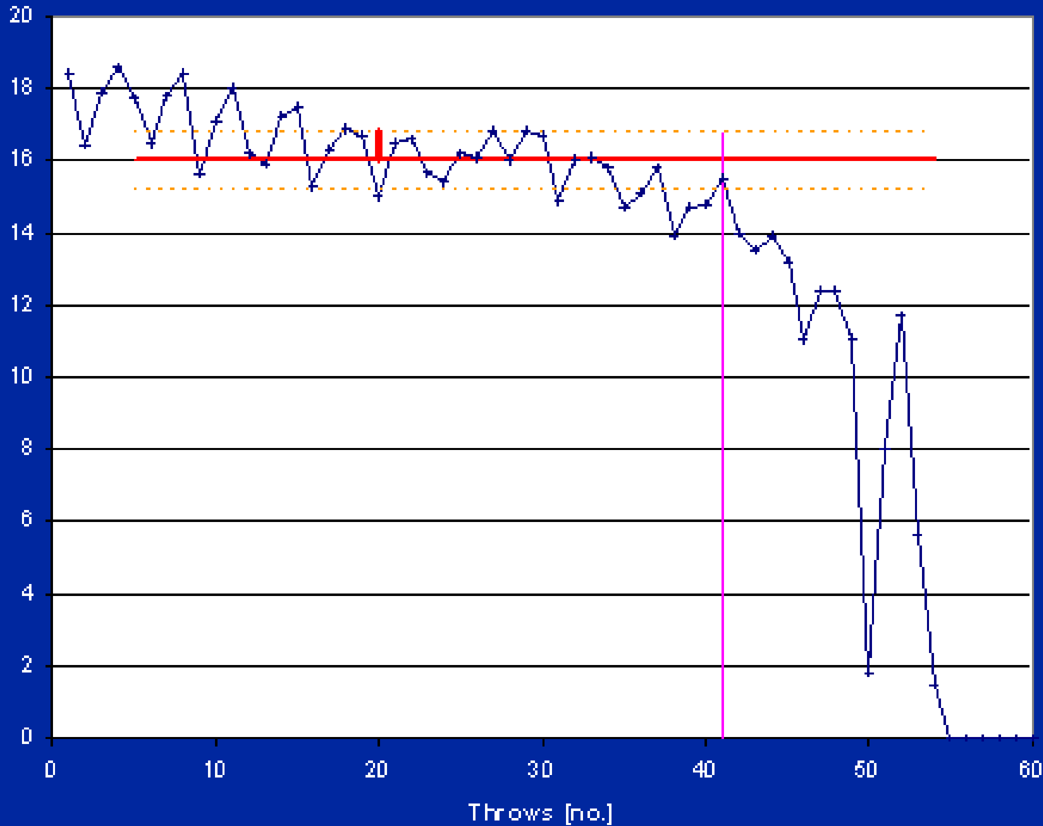
MASS FLOW

- First-in, first-out
  - Good stock rotation
  - More consistent residence time
  - Bulk density more consistent
  - Discharge rate more consistent
- Less segregation at outlet
- Promotes flow
  - Reliable discharge of cohesive material
  - Arching dimension

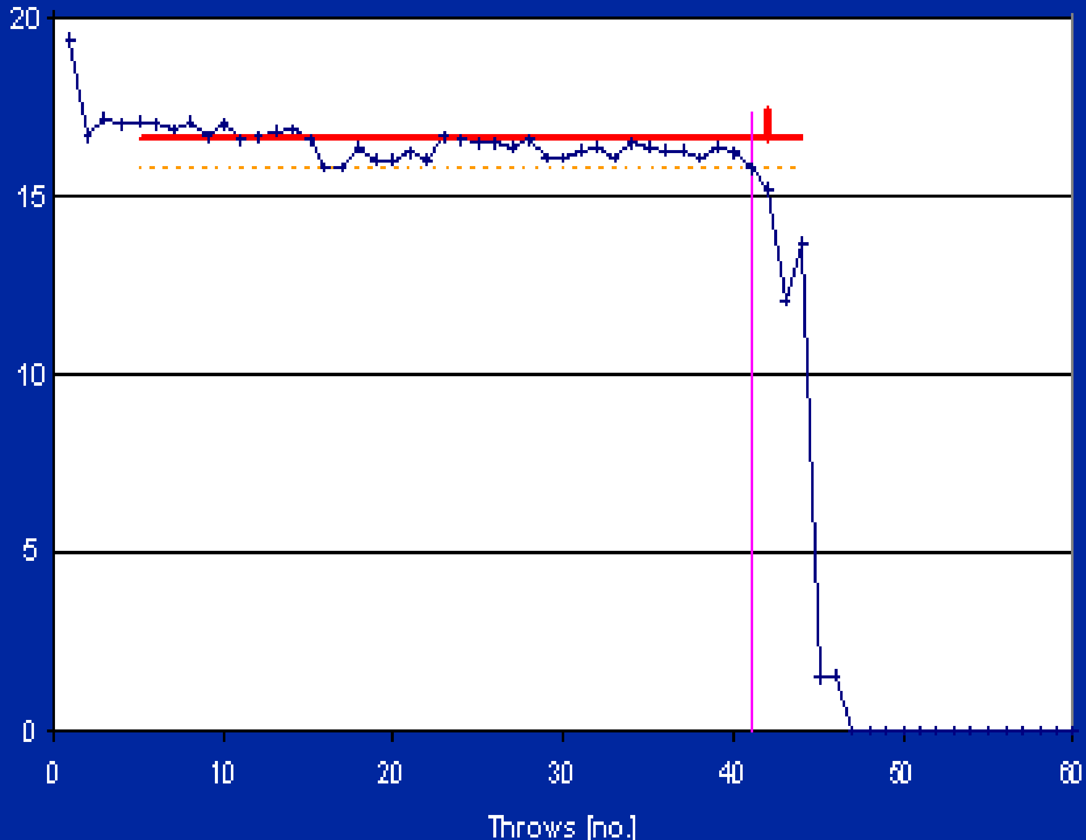


Consistency of discharge quantity:

Core Flow

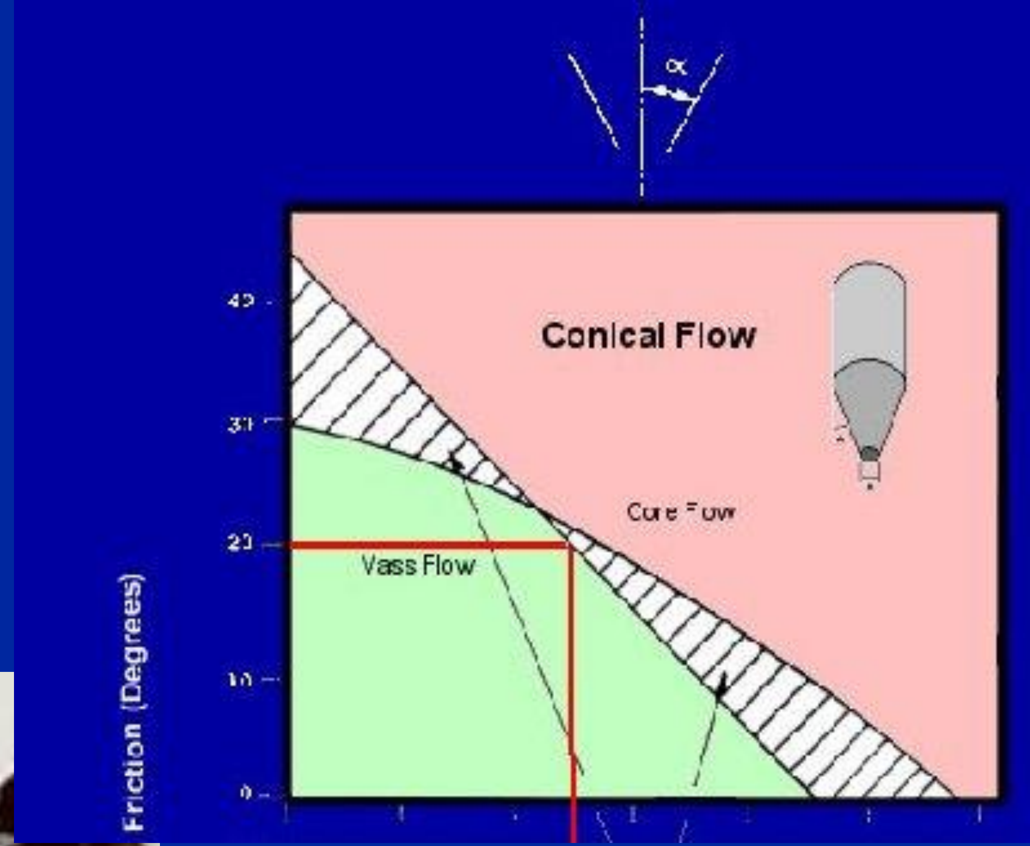


Mass Flow



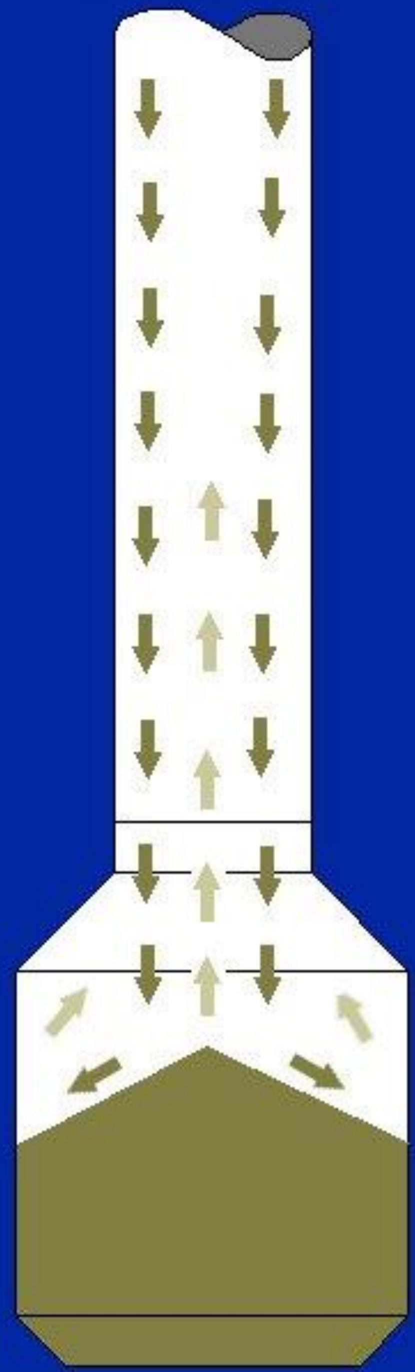
Effects of poor geometry, interfacing and feeder design

Powder characterisation measurements for flow

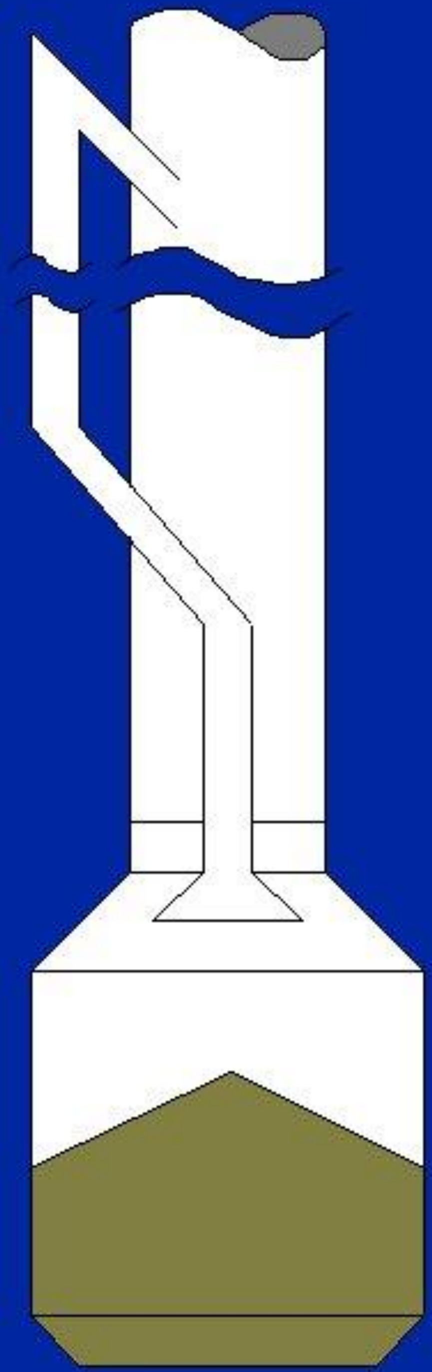


Mass or core flow?

- **Statified segregation as a result of elutriation effects**



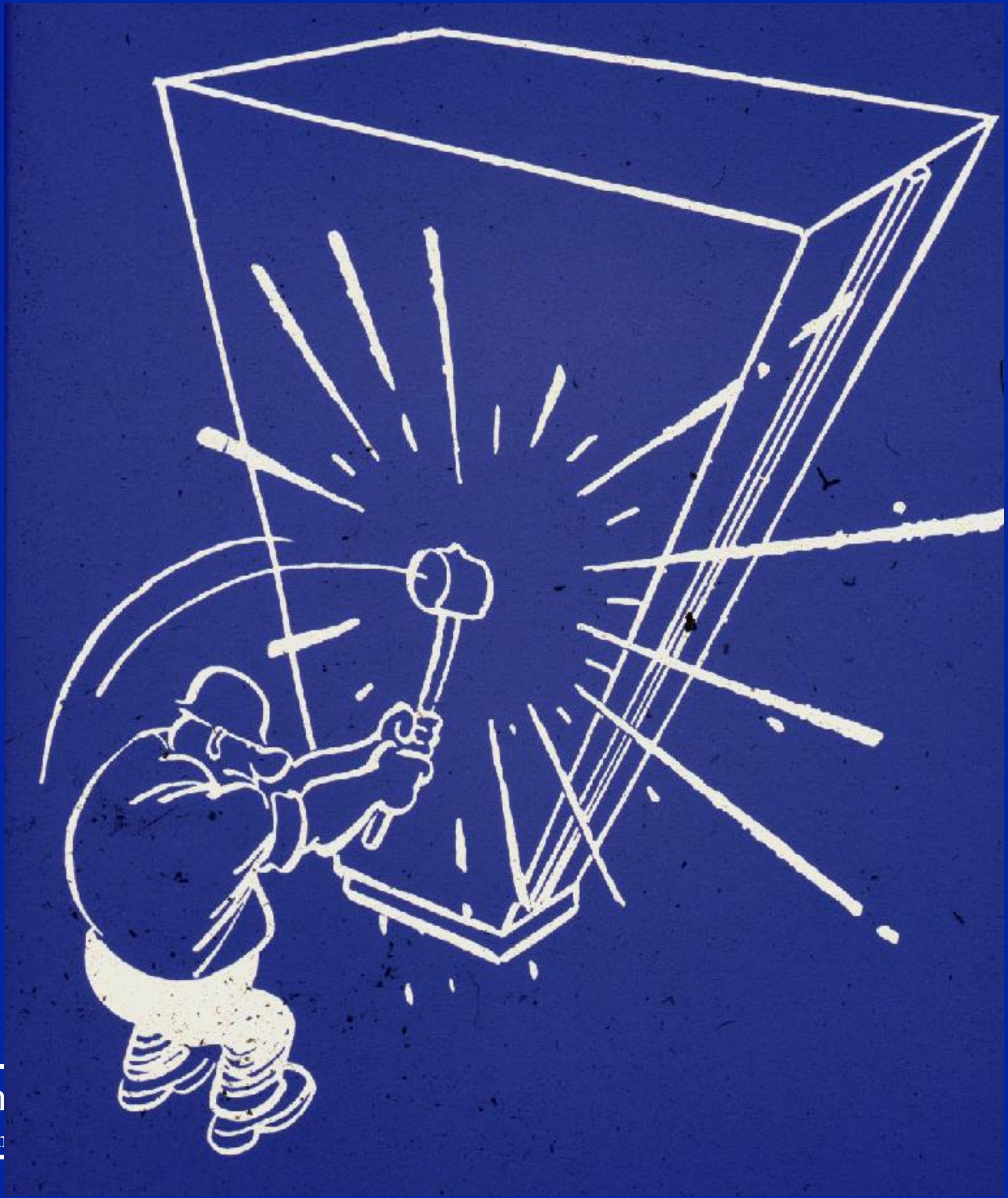
◆ **Vent arrangement to minimise entrainment of fines**



Powder flow issues

Finer powder

- More surface area
- More forces between particles
- More potential for hang-up or irregular flow
- Lower density
- Less gravity force
- More hang-up
- More frictional



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Core Flow


IT IS MANDATORY
TO WEAR EAR
PROTECTION WHEN
HAMMERING
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Poor flow from lack of proper design

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Preventing powder flow issues

Correct flow pattern

- Shape and angle convergence must be suited to friction between powder and wall
- Affected by material and finish in convergence

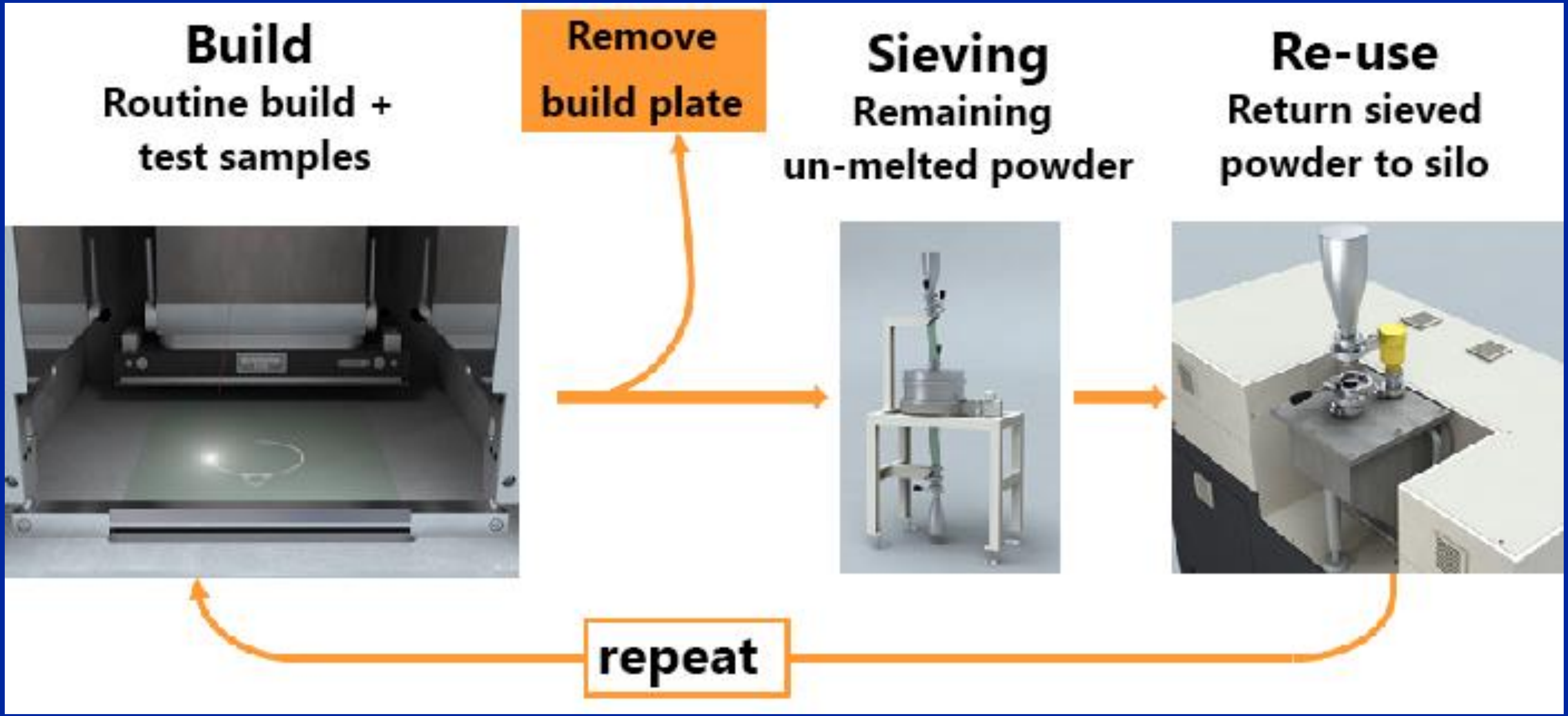
Prevention of arching or rat-holing

- Outlet size above critical dimension for powder
- Use of feeding mechanism if powder must go into smaller dimension

- *Suit the powder to the machine – or the machine to the powder*

Common problem

- Lack of attention to flow pattern in bins, hoppers, chutes and ducts
- Results
  - Segregation
  - Irregular/unreliable flow
  - = *Poor product quality*



Powder recycle

- Recycle is at the heart of the powder AM process
- "Unsintered" powder is still loosely sintered
- Effect of breaking up the bonds
  - Agglomerates and satellites
  - Particle degradation –change in particle shape, size distribution, segregation
  - Surface oxidation

Cross contamination

- Need to clean the machine when changing powder grades
- Lots of places for the powder to adhere and hide!

Spreading of powder on the bed

- Only after all the other issues above are correct, can this be optimised!

Study on the effect of

- Spreader blade type
- Square edge versus radiused
- Radius of nose
- Powder top size
- Bed thickness

Variables

Spreader nose radius:

- 0, 6, 10, 16 mm

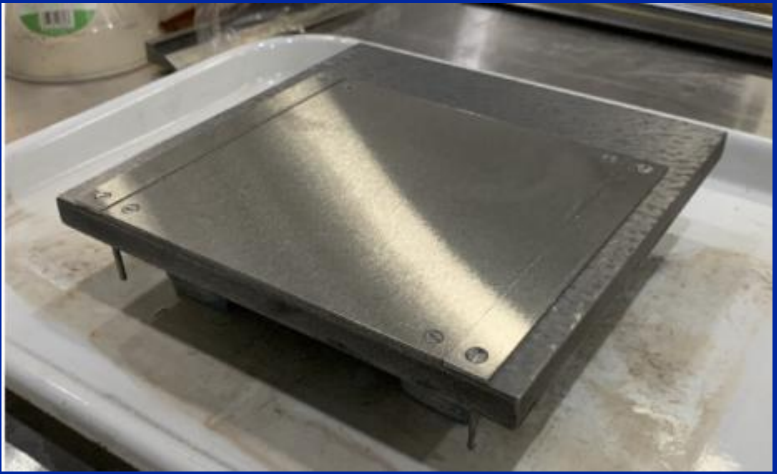
- Powder:

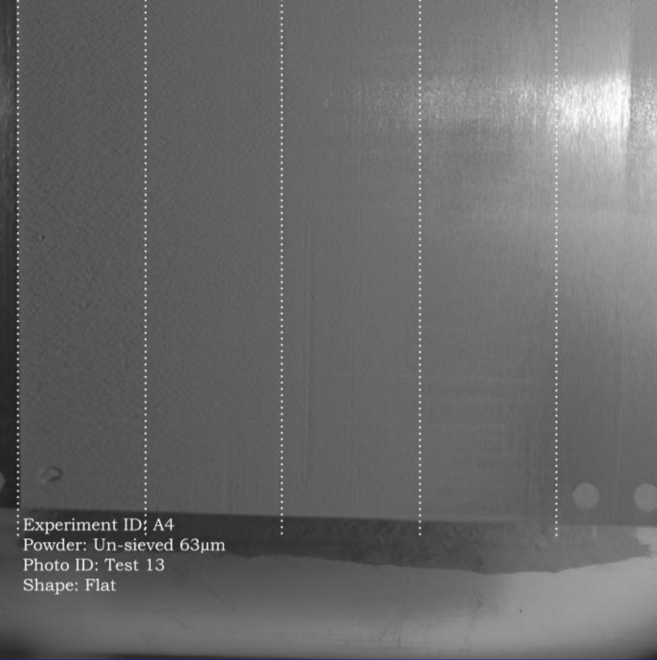
Aluminium 7050

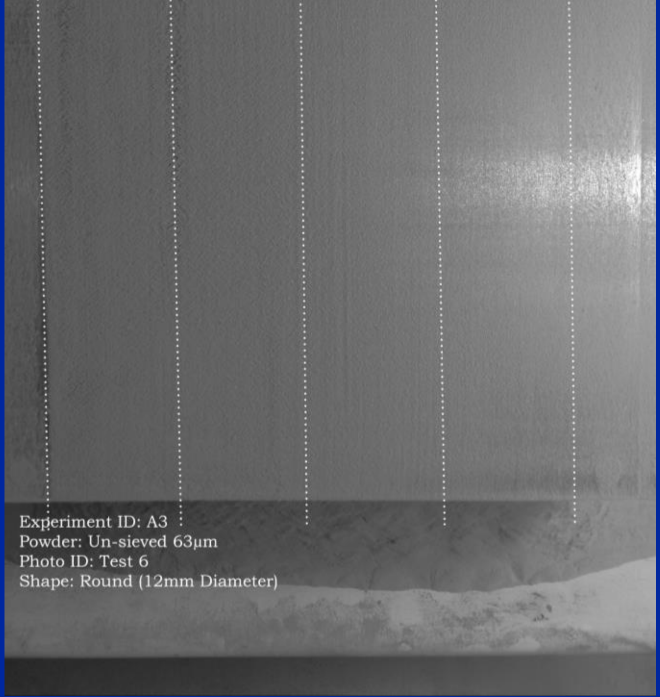
Nominal 63 micron top size

- As supplied
- Sieved at 63 microns
- Sieved at 45 microns

- Bed depth:
- 0-500 microns



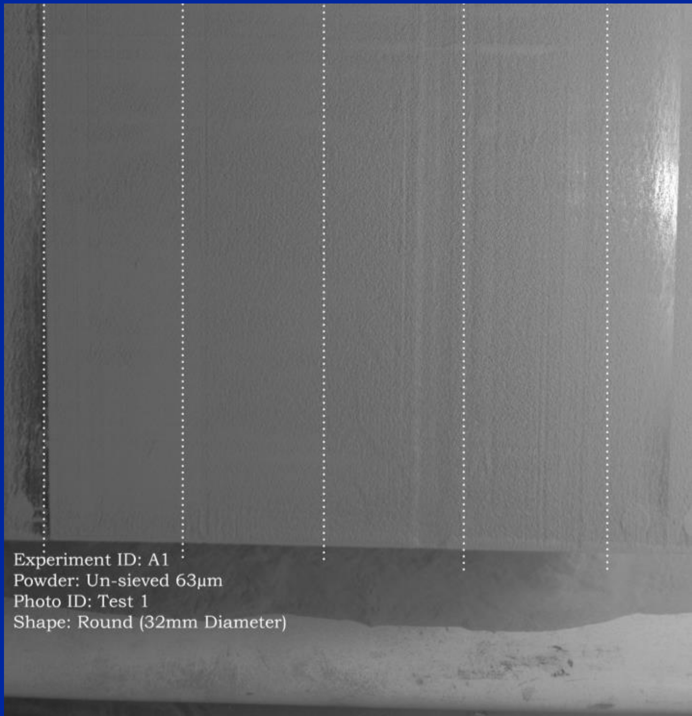




Distributor blade nose radius

As-supplied powder:

- Flat worst
- 10mm radius best for low film thickness (0-300 micron)
- 16mm best at high thickness (500 micron plus)
- Dense packing even at low film thickness
- Fewest “striations” at all thicknesses



Powder fineness

Powder re-sieved at 63 microns:

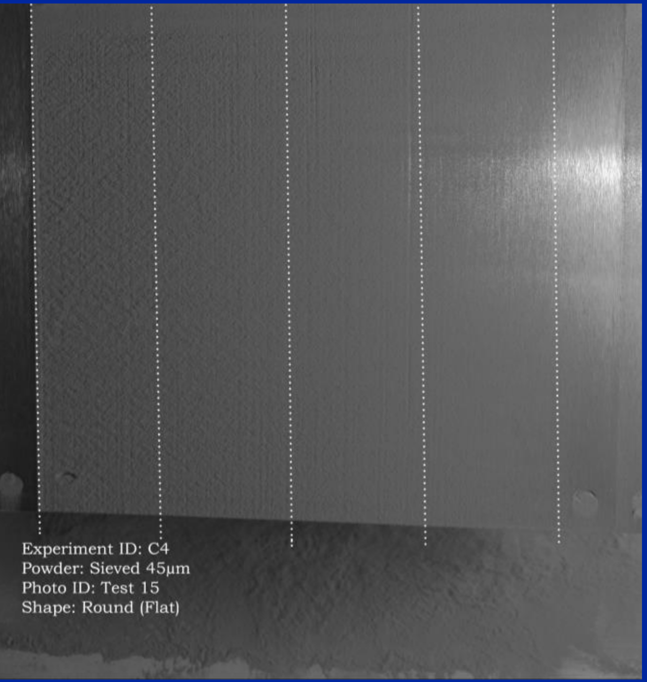
- Better behaviour across the range

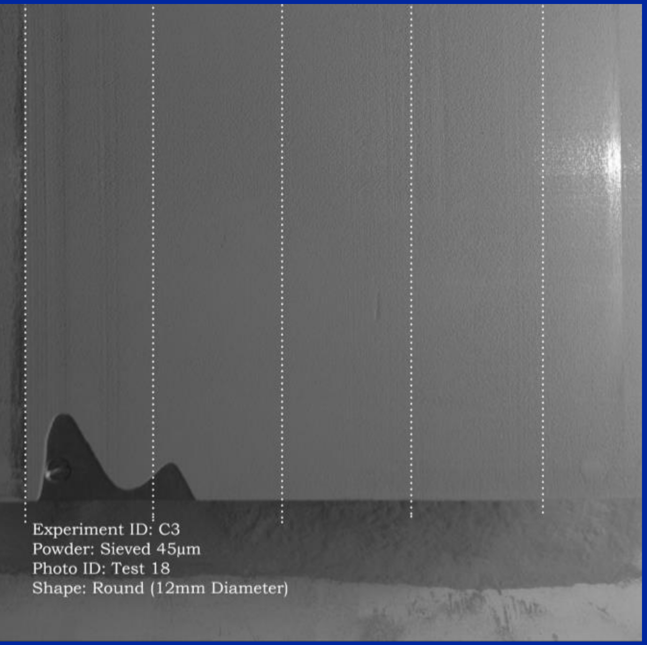
Sieved to 45 micron top size

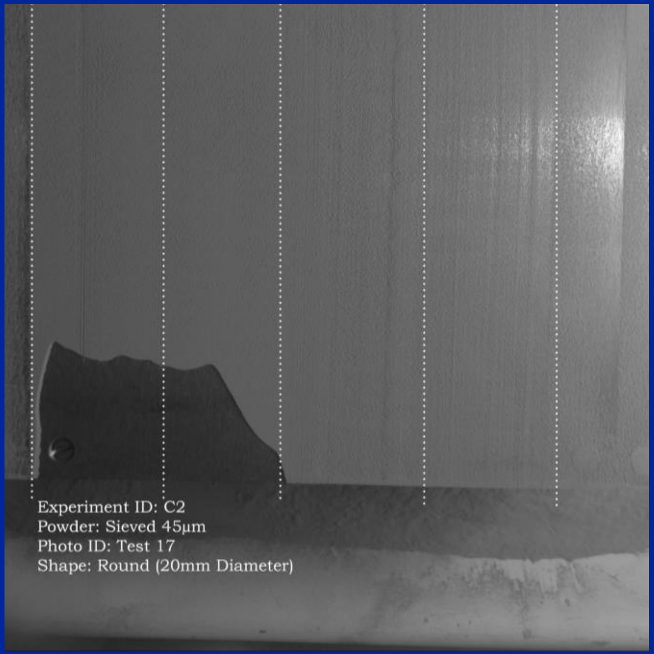
- Capable of producing densest layer at low thickness
- Much more dependent on nose radius

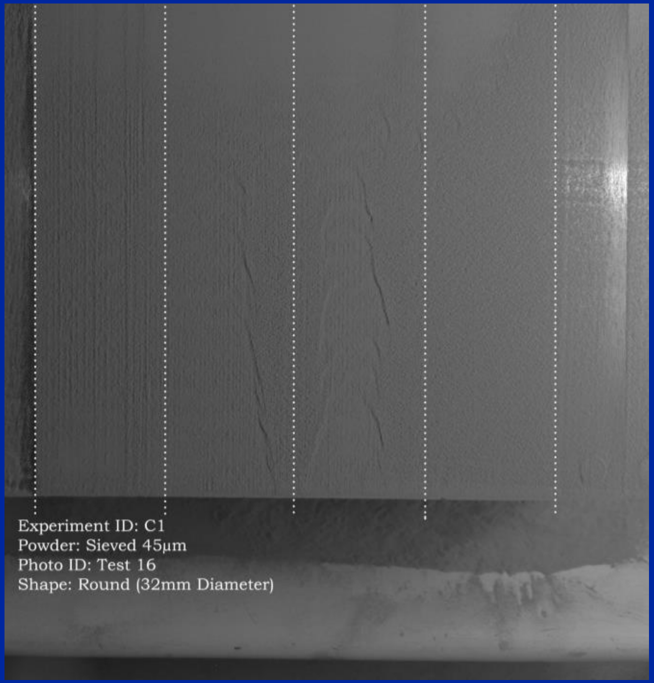
New features caused by cohesion:

- “Wedging” failure above 300 microns
- “Rippling” with large radius









Spreadability limits of powder

ID	Powder Type	Scraper	Spreadabilty Limit (μm)
A1	Un-sieved	Round (Diameter 32mm)	130
A2	Un-sieved	Round (Diameter 20mm)	150
A3	Un-sieved	Round (Diameter 12mm)	210
A4	Un-sieved	Flat	380
B1	Sieved 63μm	Round (Diameter 32mm)	130
B2	Sieved 63μm	Round (Diameter 20mm)	110
B3	Sieved 63μm	Round (Diameter 12mm)	180
B4	Sieved 63μm	Flat	180
C1	Sieved 45μm	Round (Diameter 32mm)	90
C2	Sieved 45μm	Round (Diameter 20mm)	200
C3	Sieved 45μm	Round (Diameter 12mm)	120
C4	Sieved 45μm	Flat	200

- **Function of powder fineness and cohesiveness**
- **Also nose radius is critical**
- **How does optimum spreader design vary with powder properties? *Current research!***

Fundamentals

- Make sure powder flows against surfaces – not powder against powder
  - Design with principles of mass flow
  - Knowledge of powder/wall friction properties
  - Investment in better wall materials
- Avoid back flow of displaced air through powder
  - Vent confined spaces
  - Design for slow let-down

Where are we with exploitation?

- Much of this is not news to researchers in the field of POWDERS
- Theories of powder flow work – proven over tens of thousands of installations
- Exploitation very patchy
  - Many suppliers of powder processing equipment do not use the theory
  - - because many buyers do not understand the need for it, so don't demand it!
- AM must start to recognise the need to learn good powder handling practice, not make mistakes!

CONCLUSIONS

- Much time and effort is spent on producing just the right blend of powder
- Most of the loss of quality occurs in transfer from blender to process, and powder recycling
- All the problems have solutions
- Measure the powder behaviour
- Select the right hardware to avoid problems

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