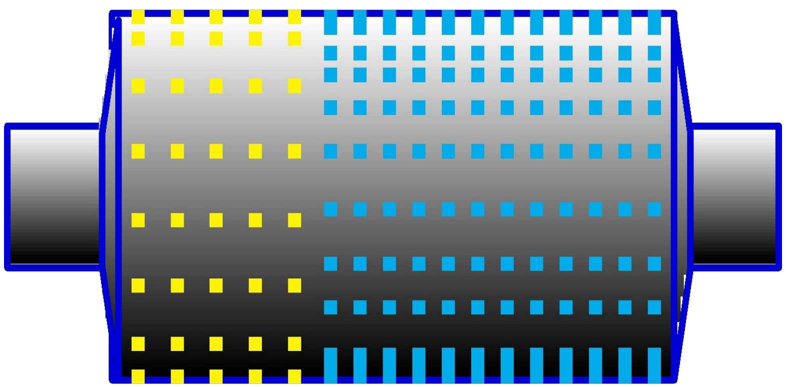
Ball Charge Design and Management

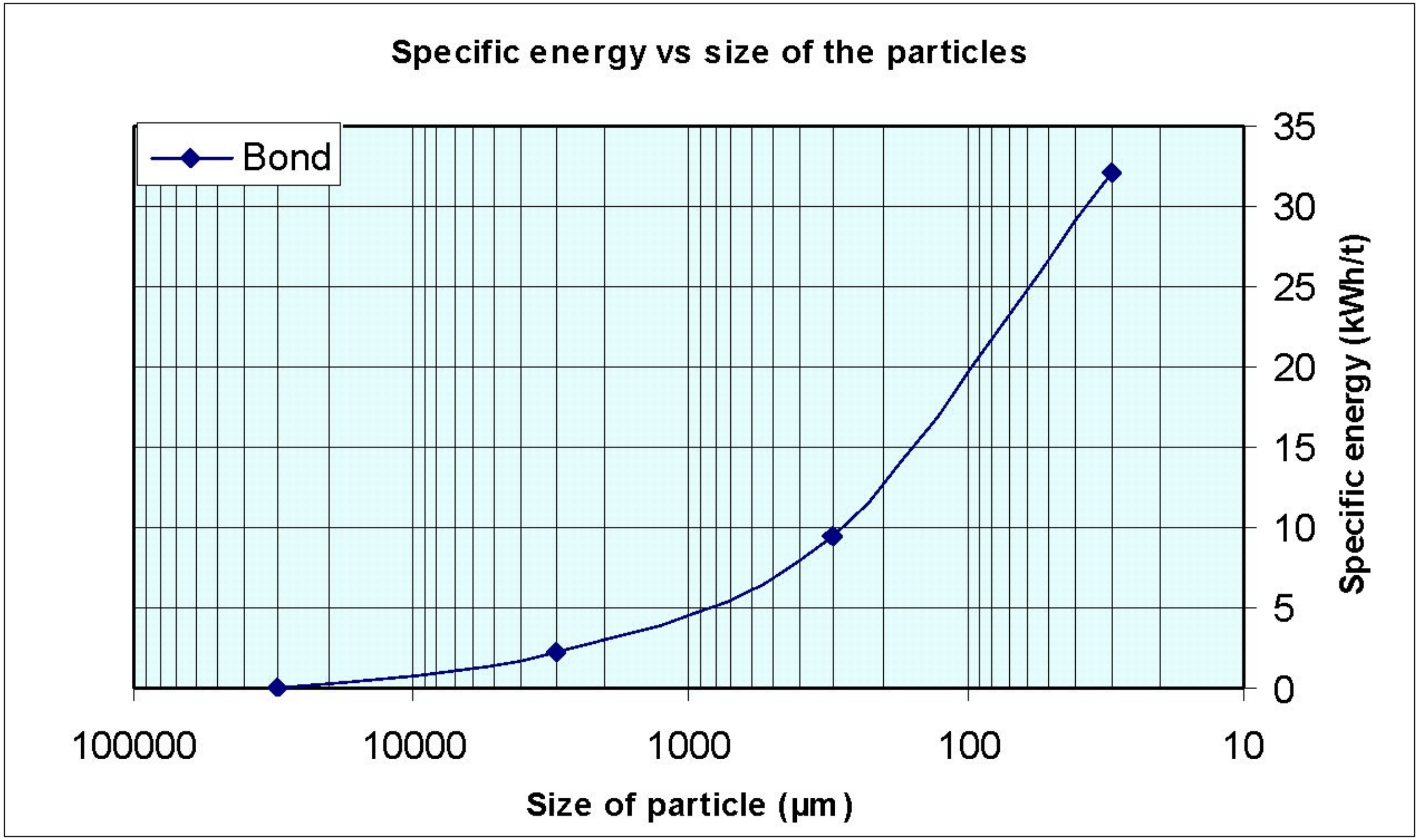


LAFARGE CEMENT

EUROPE TECHNICAL CENTER

Grinding is a transfer of energy…

$$Wb = Eb \times \left(\frac{10}{\sqrt{D80_f}} - \frac{10}{\sqrt{D80_i}} \right)$$



30mm □ 3mm

2 kWh/t

3mm □ 300µm

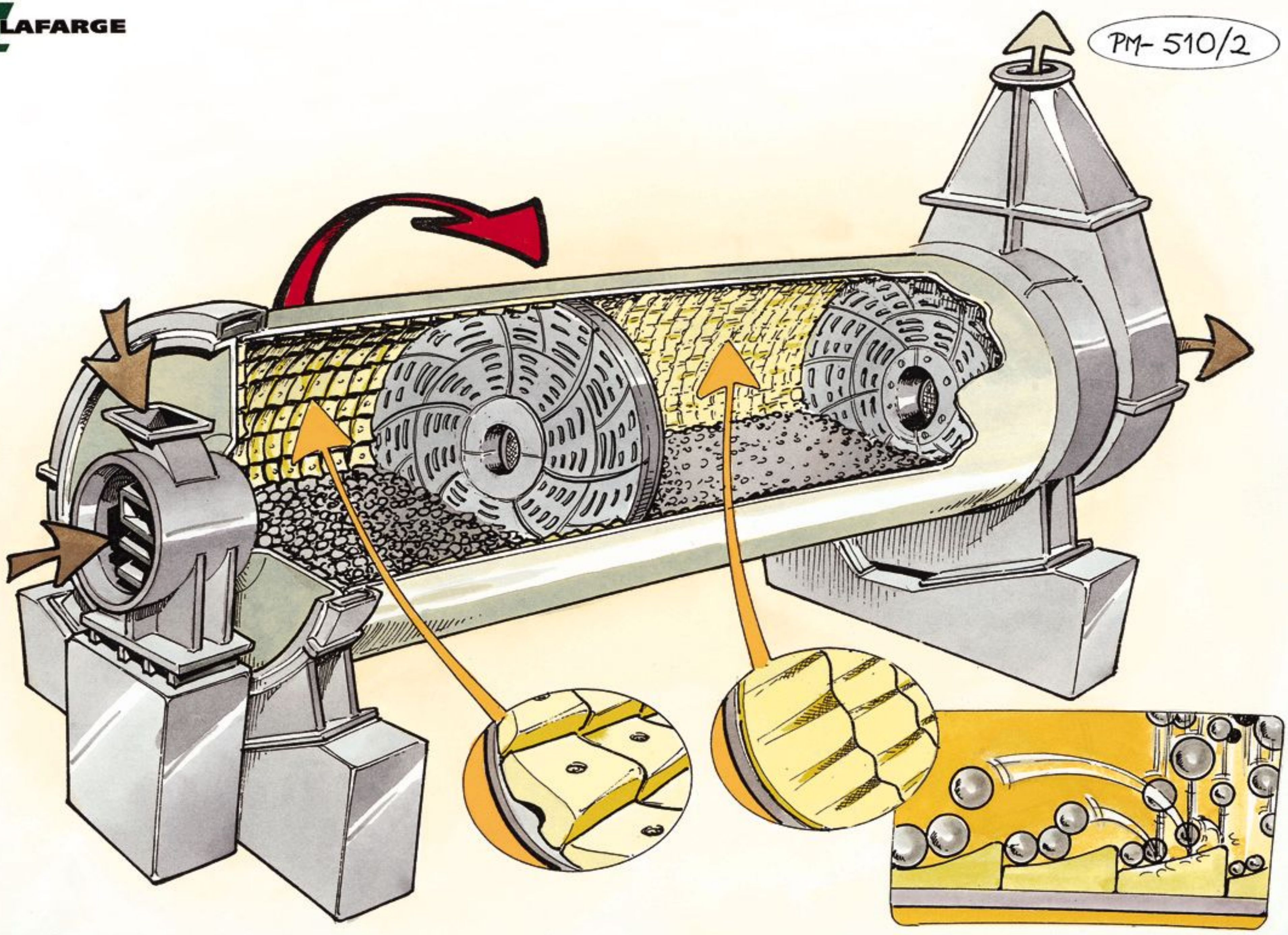
6 kWh/t

300µm □ 30µm

24 kWh/t

LAFARGE

PM- 510/2



… throught the movement of balls…

$$P = M \cdot \omega = b \cdot Q \cdot \omega$$

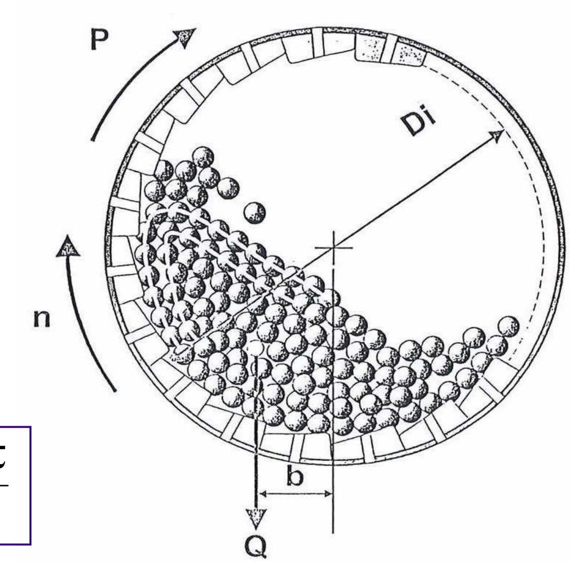
Assumptions: lever b is proportional to D_i
lever b is independent from mill speed

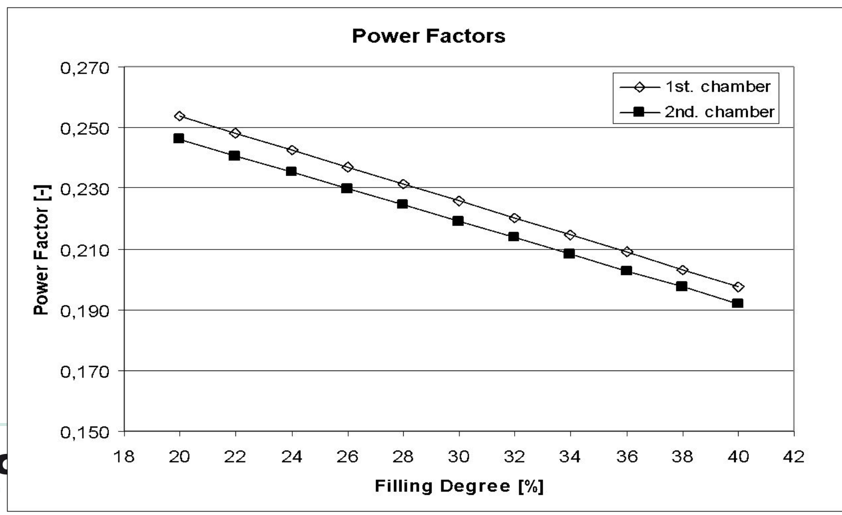
$$\Rightarrow b = x \cdot D_i$$

$$P = x \cdot D_i \cdot Q \cdot \omega = x \cdot D_i \cdot Q \cdot \frac{\pi \cdot n}{30}$$

simplified to

$$P = c \cdot D_i \cdot Q \cdot n[kW] \qquad \text{with} \qquad c = \frac{x \cdot \pi}{30}$$





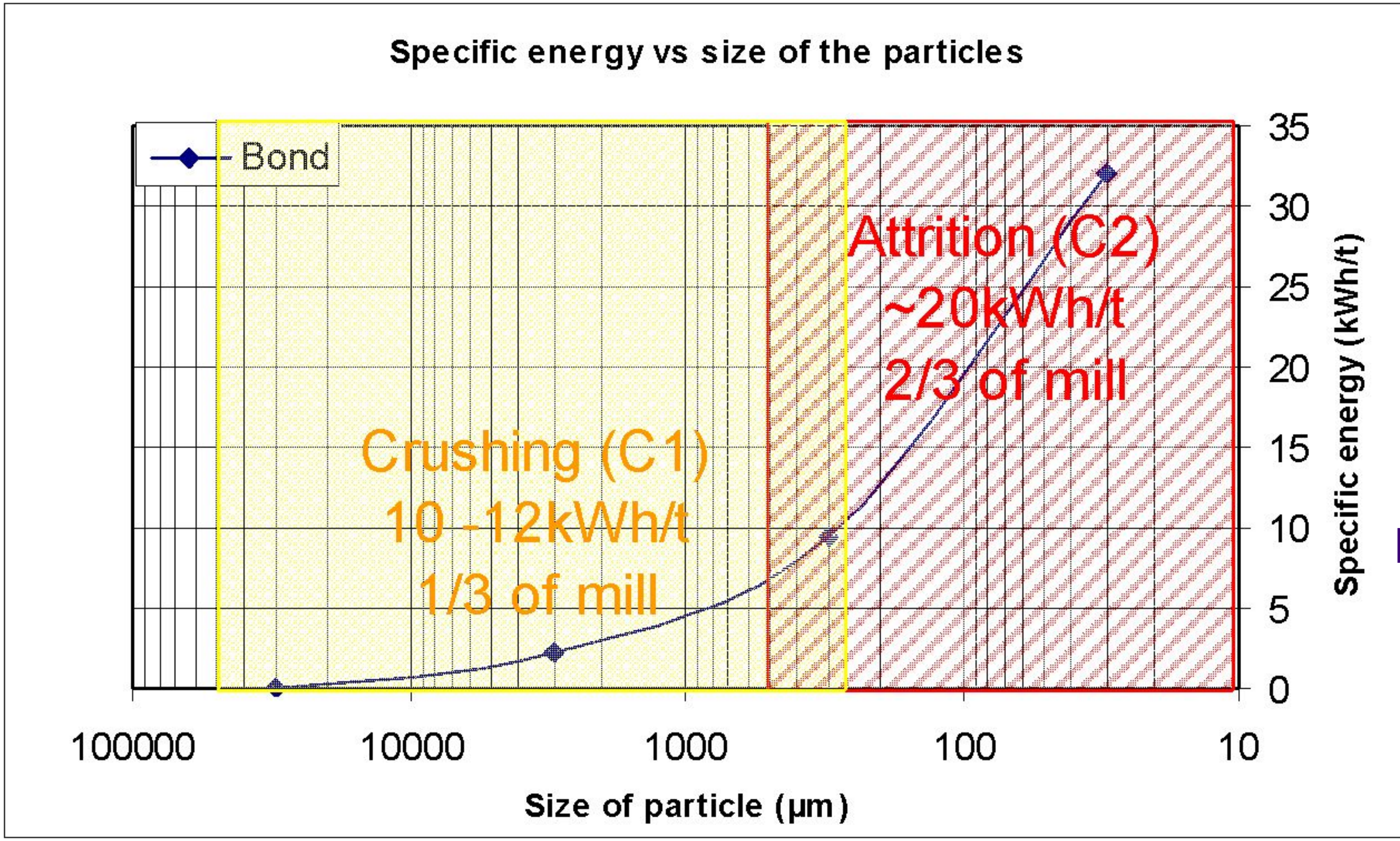
c = power factor [-]

Q = Mass of ball charge [t]

D_i= usefull diameter [m]

n = speed of mill shell [rpm]

… with a poor efficiency (95% lost in heat)



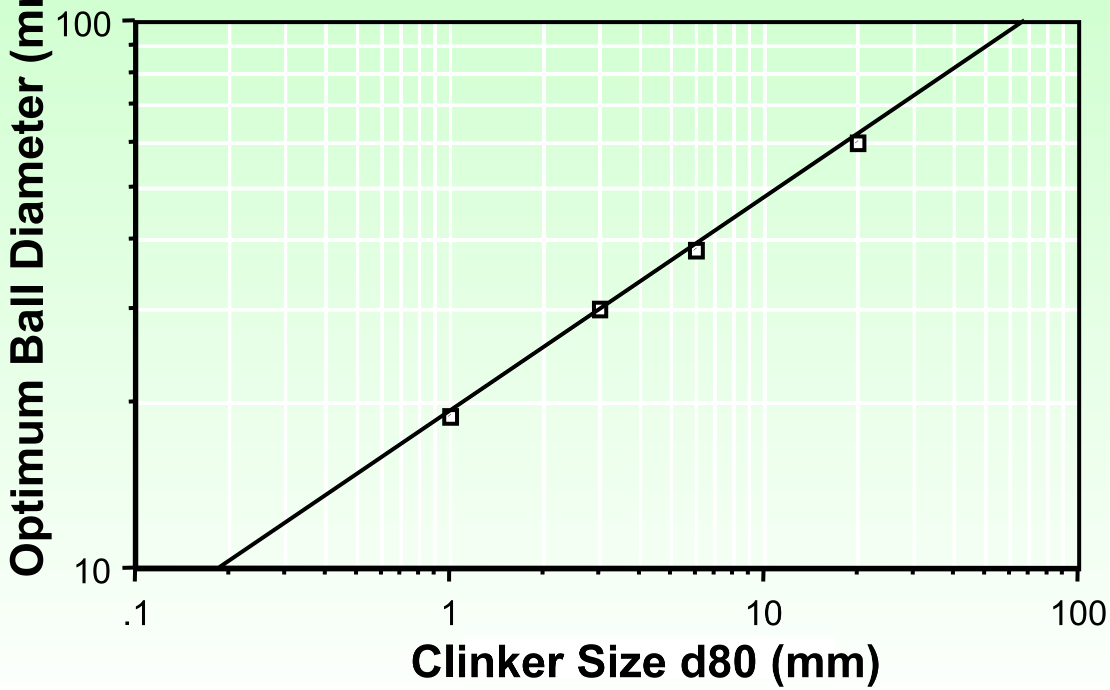
50mm ~ 0,5mm
Crushing is more efficient

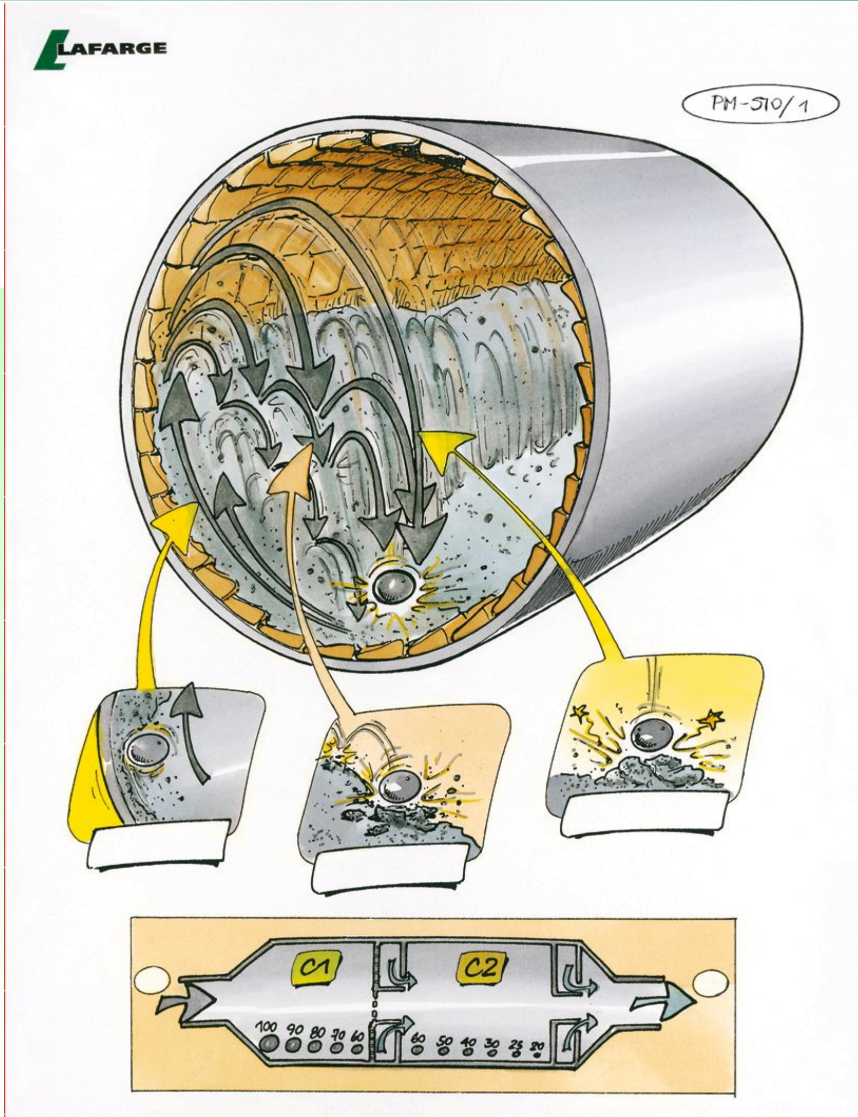
Under ~0,5mm 5µm
Grinding by attrition

Rule
Max 5% residues at mesh 2,5mm at the end of C1

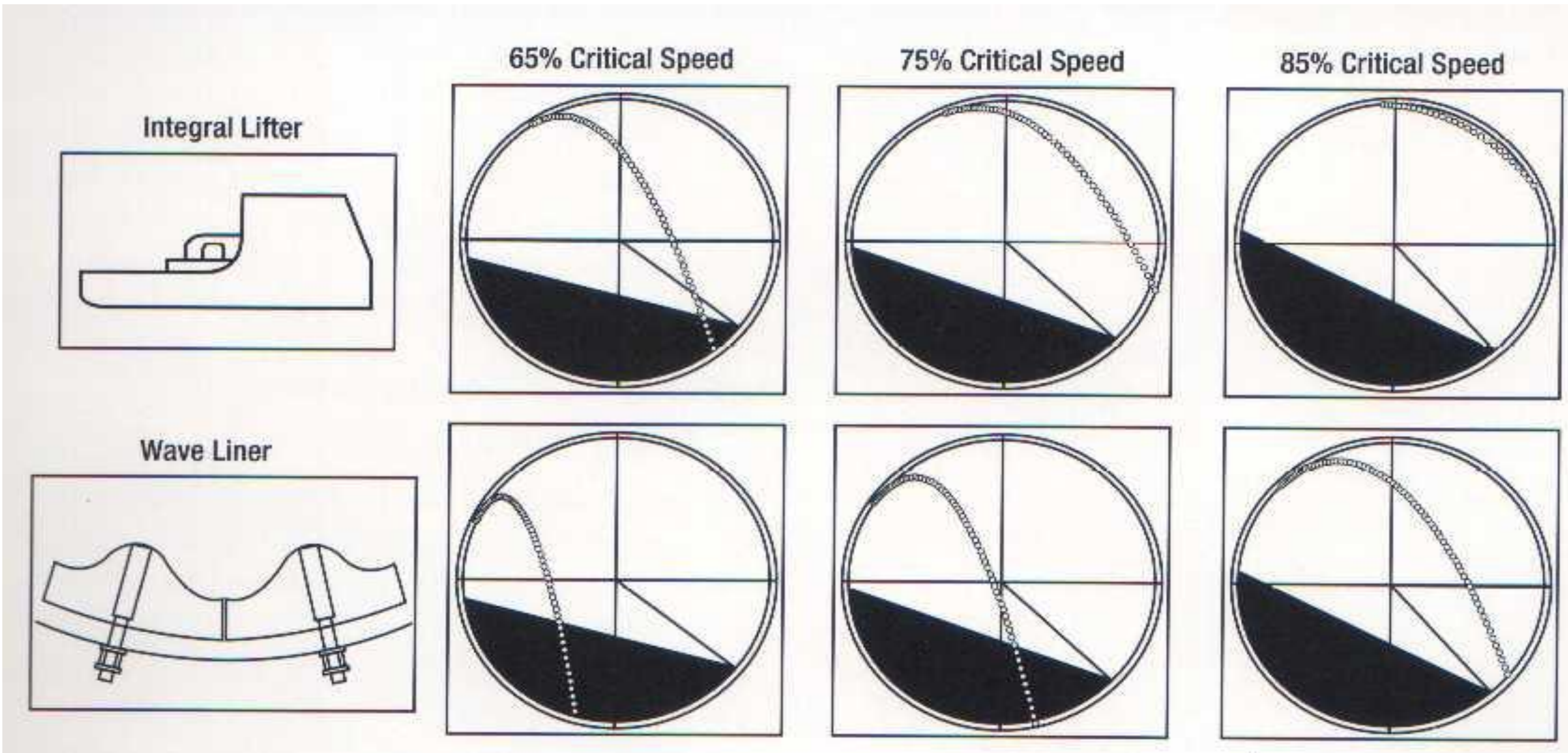
Matching Ball Sizes…

Grinding Ball vs Clinker Size

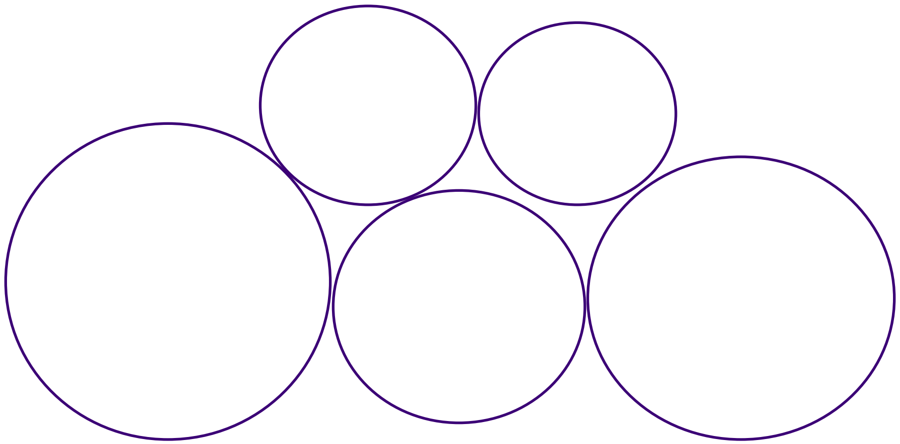




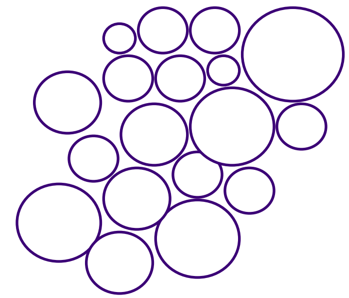
… without forgetting the effect of the liners



Porosity



Coarse balls - large voids low retention



Fine balls - small voids high retention

- **Average ball weight**
  - total charge weight / total number of balls
  - kg/ball

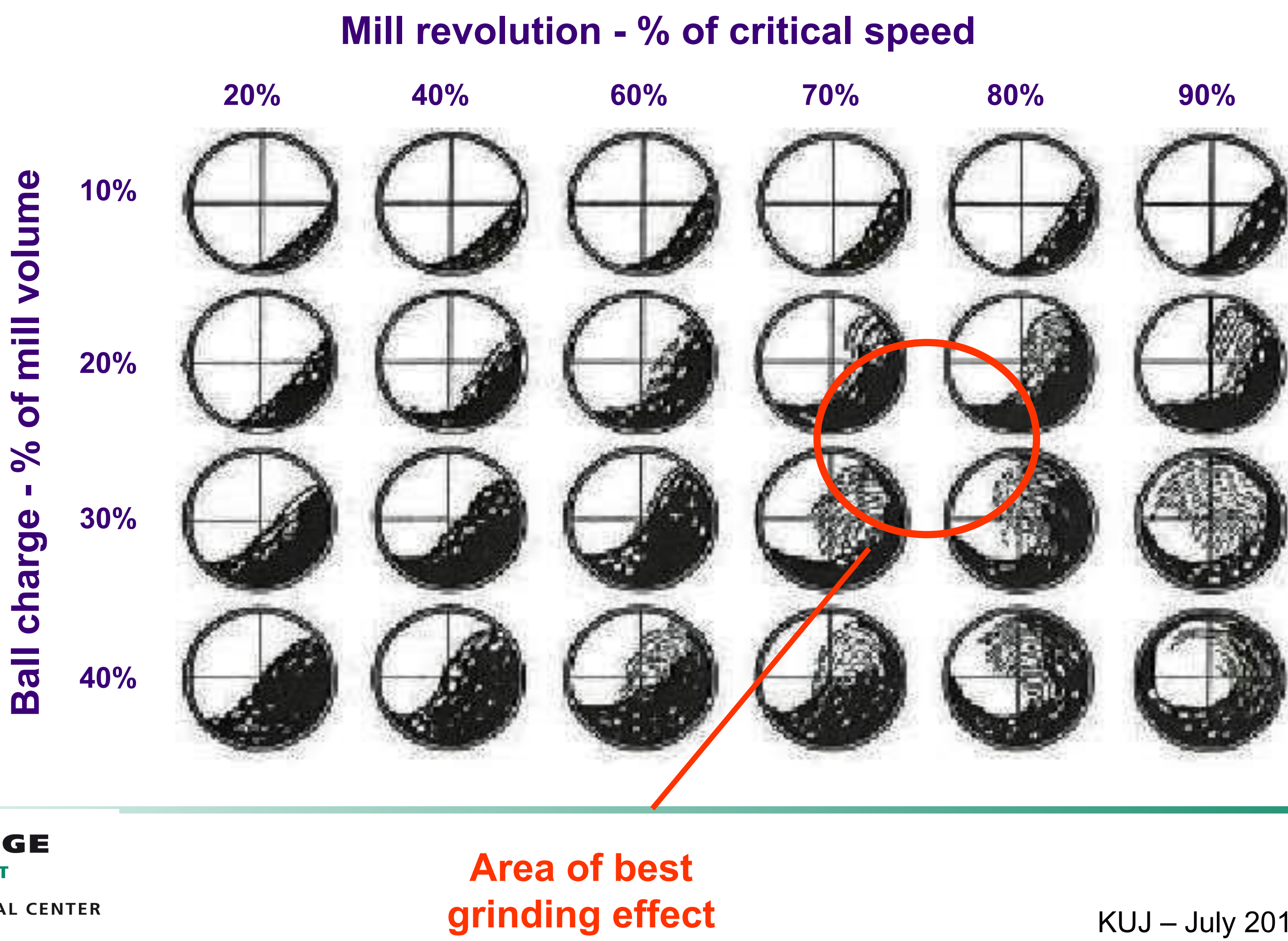
- **Specific surface area**
  - total surface area / charge weight
  - m^2/ton

LAFARGE CEMENT

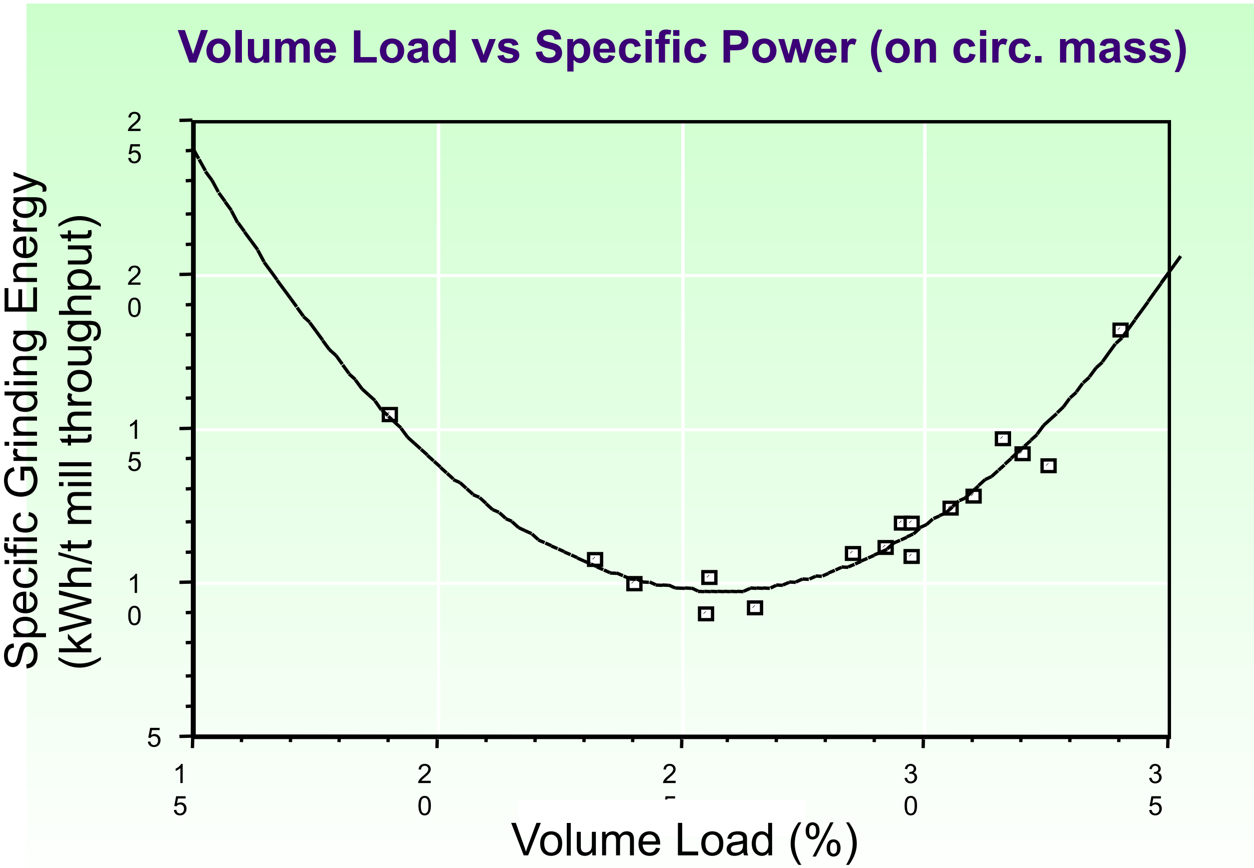
EUROPE TECHNICAL CENTER

Volume loading

Ball movement according filling degree / critical speed



Ball volume loading



VL = approx. 25%

- Minimum Grinding Energy (kWh/t)

Following filling degree

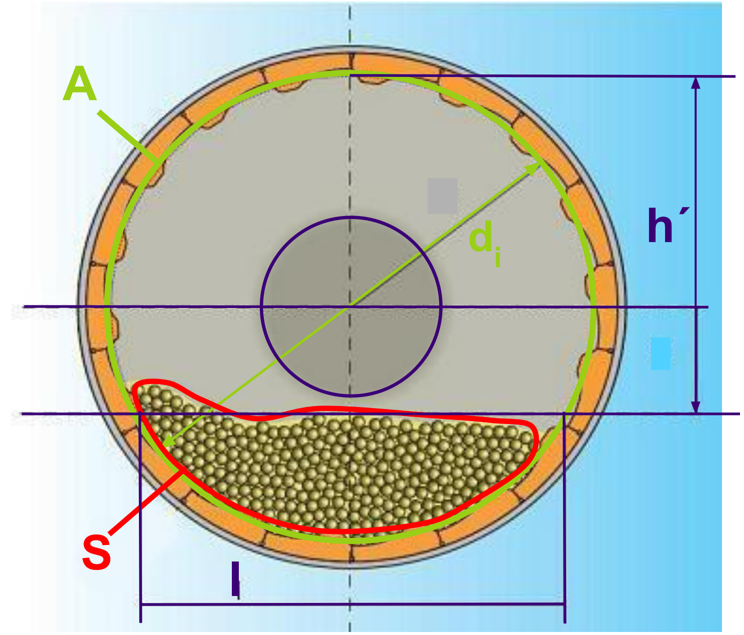
$$F = \frac{S}{A} \cdot 100 [\%]$$

The required surface area [S] can be calculated by:

$$S = \frac{d_i - h'}{6 \cdot l} \cdot \left[3 \cdot (d_i - h')^2 + 4 \cdot l^2 \right] \; [m^2]$$

The string value [l] can be calculated by:

$$l = \sqrt{8 \cdot (d_i - h') \cdot \left[\frac{d_i}{2} - \frac{(d_i - h')}{2} \right]} \; [m]$$



A = Free surface

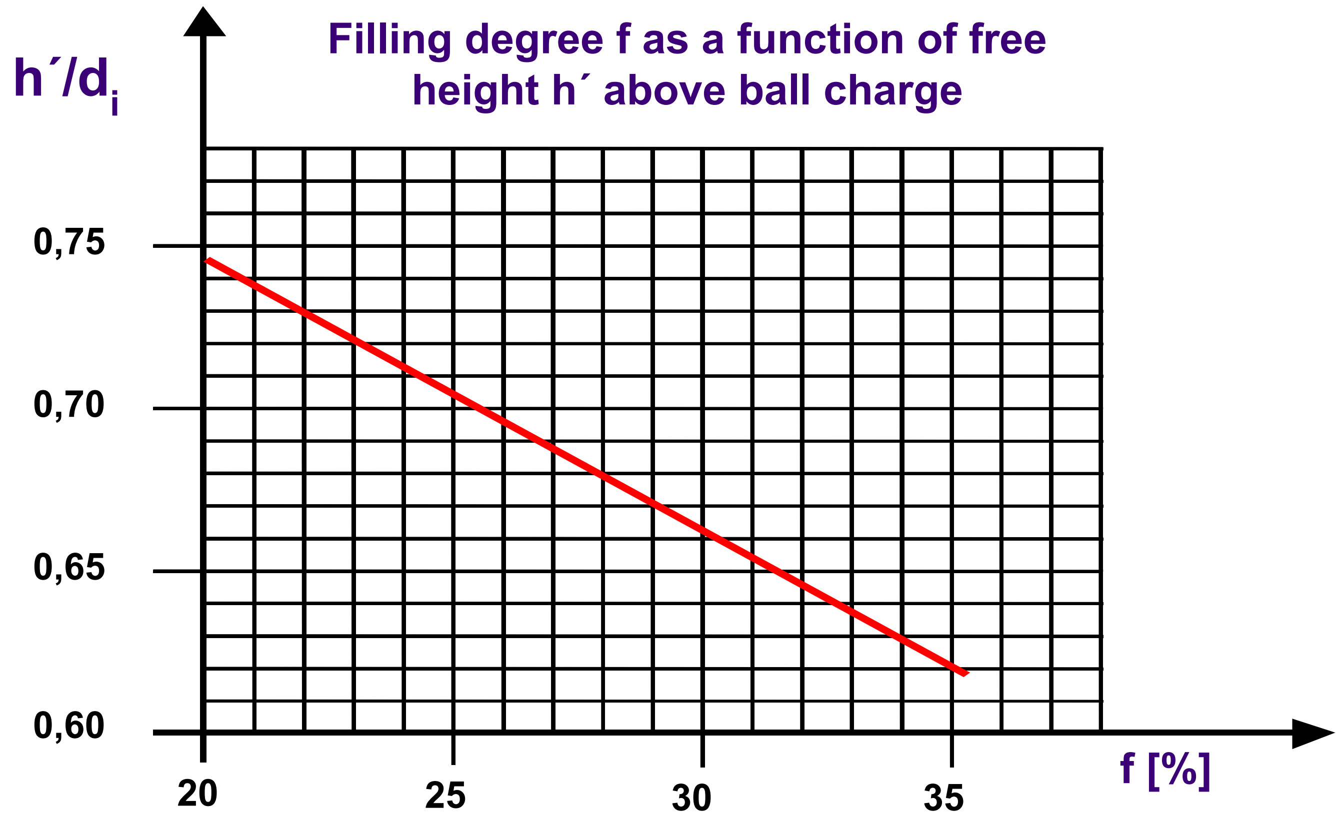
S = Surface area of charge

The filling degree can be calculated by measuring the free height [h'] and the clear inside diameter [d_i] only.

LAFARGE CEMENT

EUROPE TECHNICAL CENTER

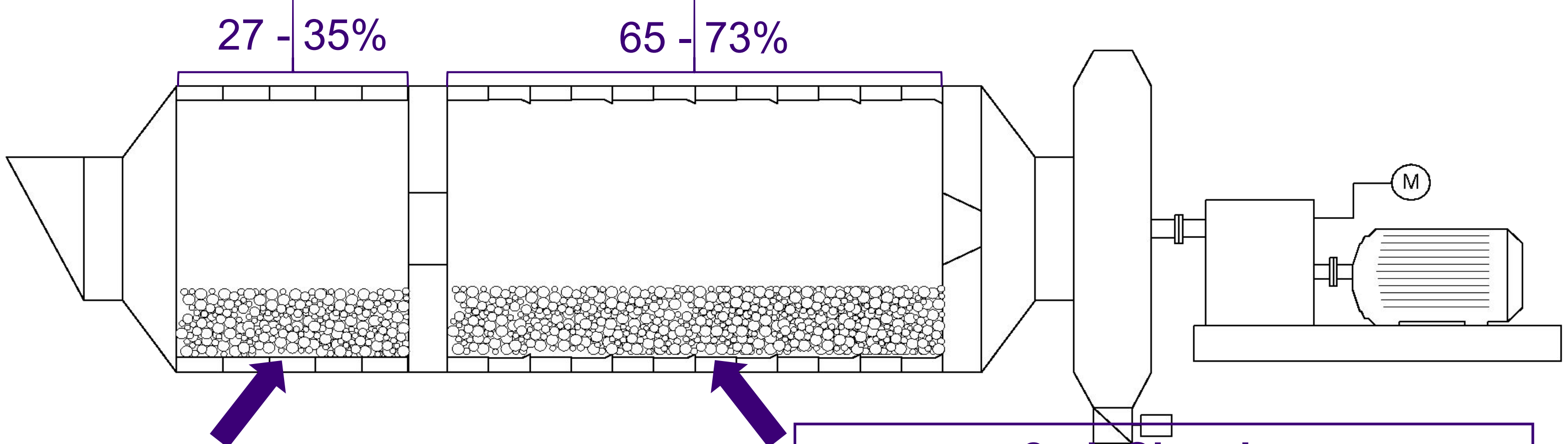
Calculation of filling degree



LAFARGE CEMENT
EUROPE TECHNICAL CENTER

Chamber length / Ball charge

Length to diameter ratio (for OPC): $\frac{L}{D} \approx 3{,}0 - 3{,}5$ (closed circuit) $\frac{L}{D} \approx 3{,}5 - 5{,}0$ (open circuit)



1st. Chamber

30 – 32%	**volume load**
8 – 12 kWh/t	**specific power**
10 – 12 m²/t	**specific surface**
1,6 – 1,8 kg/ball	**cement mill**
1,5 – 2,0 kg/ball	**raw mil**
4,55 t/m³	**bulk density**

2nd. Chamber

28 – 32%	**volume load**
20 – 24 kWh/t	**specific power**
28 – 34 m²/t	**specific surface**
50 - 60g/ball	**cement mill**
150 - 200g/ball	**raw mil**
4,70 t/m³	**bulk density**

Ball Charge Fundamentals

- **In a ball mill, the balls grind the material**
- **Match the charge to the material particle size**
- **The ball charge has a major effect on material progression in the tube**
- **Adjust the mill charge porosity or permeability, to the amount of circulating load and throughput required**
- **Adjust the level of charge, or volume loading, to optimize production and efficiency.**

How to design a ball charge and manage it?

Calculation of a theoretical ball charge

(always involve your Technical centre)

Optimisation of a ball charge in an existing mill

(better to involve Technical centre)

Ball charge management and follow-up

Theoretical ball charge

- **Parameters**
  - Product: type, composition, fineness, throughput…
    - the ball charge design must produce the maximum output of different types of optimum quality cement. The charge should be adjusted to the type most produced.
  - Material characteristics: crushability, grindability, size, moisture…
  - Mill: L/D, power available, internals, speed, ventilation…
    - Whenever possible, the design should try to minimise the risk of metal to metal contact and thereby the wear rate of components

Always take into account possible variations of these parameters

Design methodology

- **Numerous attempts to make the process more scientific and rigorous**
  - Slegten, Polysius Models
  - Lafarge Corp. Mill Grinding Reference
  - Effort continues with Best Practices

- **Efforts are hampered by lack of**
  - Raw material testing data
    - Crushability, feed size
  - Consideration for mill & circuit design/condition
    - Liner type & condition, mill sweep, separator type

- **Lack of extensive trial & validation programme**
  … but methods can be a useful guide!

Design methodology

Definition of the volume loading

↓

Calculation of the tonnage in each chamber → Chambers internal dimensions; Ball charge bulk density

↓

Calculation of the largest ball size → BOND formula; Granulometry of the feed material (D80)

↓

Apply model → Slegten or Polysius

Ball volume loading

	1st compartment	2nd compartment
Minimum kWh/t	26 – 28%	28 – 30%
Maximum Production	32 – 34%	34 – 36%

- The recommended volume loading for minimum kWh/t is based on an acceptable compromise with production and by the amount of wear on the balls and liners
- The upper limits are the maximum absorbed power allowed by the drive, the maximum level of the grinding charge with respect to the trunnions and to the central partition vent opening

Experience indicates that the best volume loading for cement mills is

C1: 30 to 32%

C2: 28 to 32%

Biggest ball

Bond Formula

$$Ømax = 20,17 \, . \, \sqrt{\frac{D_{20}}{K}} \, \sqrt[3]{\frac{Wi.\rho}{\%Vc.\sqrt{Du}}}$$

where,

- Ømax = biggest ball diameter, mm
- D_{20} = sieve dimension where 20% is retained, µm
- K = constant (350 for dry mills, open or closed circuit , 300 for wet)
- ρ = specific mass of material, g / cm^3
- Wi = Bond Work Index, kWh / t
- Du = useful inside mill diameter, m
- %Vc = % of critical speed

LAFARGE CEMENT
EUROPE TECHNICAL CENTER

Ball charge design - C1

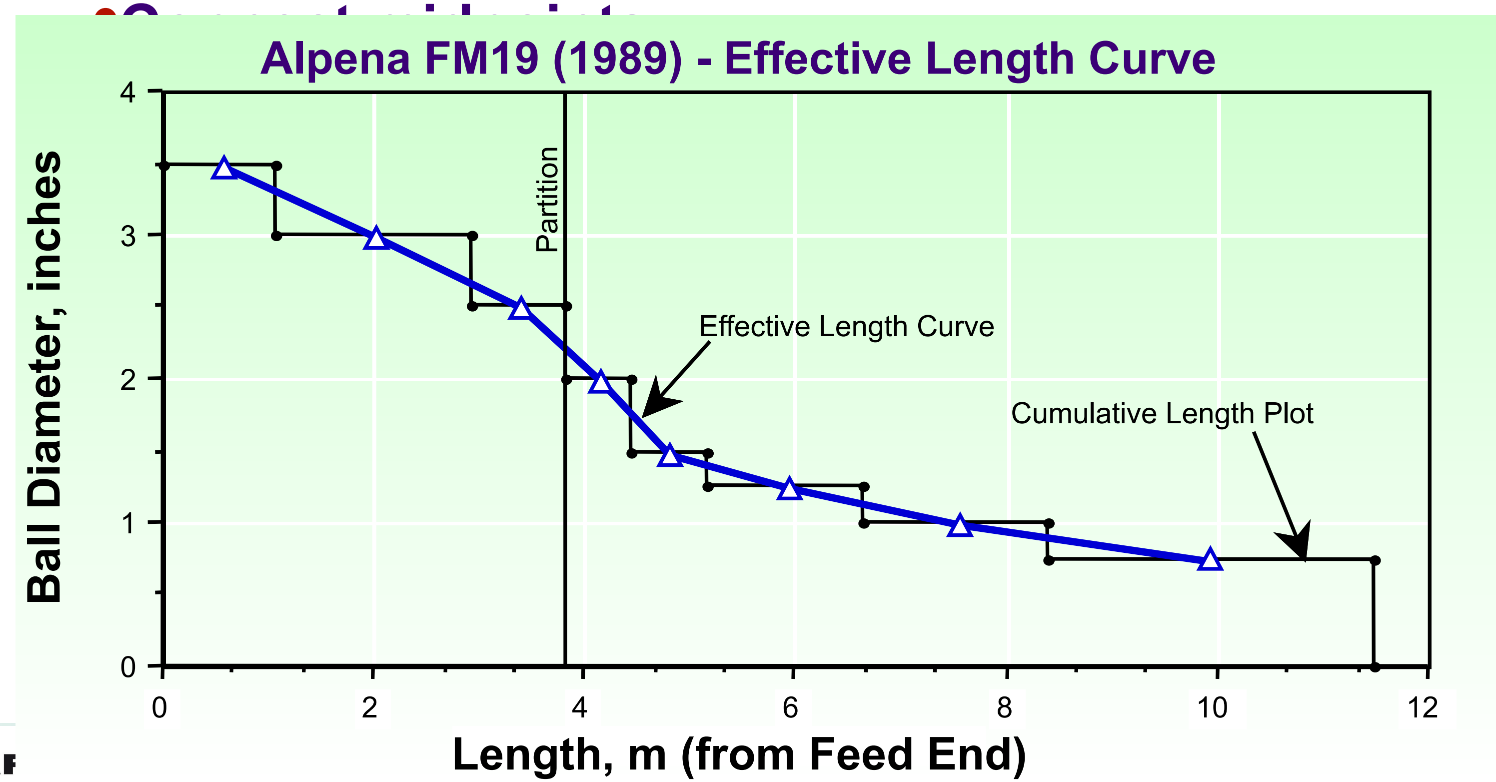
- **Emphasis on crushing and less on grinding**
- **Typical top size**
  - 80 mm Ø if easy to crush, small feed size
  - 90 mm Ø is the most common
  - 100 mm Ø in rare cases: very hard, coarse feed
- **Coarser ball charges give good crushing capability but**
  - Too porous - shorter retention
  - Less surface, less grinding
  - Can result in poor preparation for second chamber if you overfeed (usually forced to underfeed)
  - Extra wear

Ball charge design - C2

- **Emphasis on attrition grinding**
  - Cement grinding wants maximum fines generation (Blaine)
- **Top size depends on how much preparation is done in the first chamber. Recommendation : 30 ... 50 mm**
- **Smallest size depends on the discharge grate slot size**
  - Practical rule of thumb: smallest Ø = 2 X slot width
  - E.g. slot width = 8-10 mm: smallest Ø = 16-20 mm
- **Non-classifying liners limits C2 to 3 sizes (or size ratio 2:1) Classifying liners allow a large variety of Ø's**
- **Best Practice "Ball Charge Level Management"**

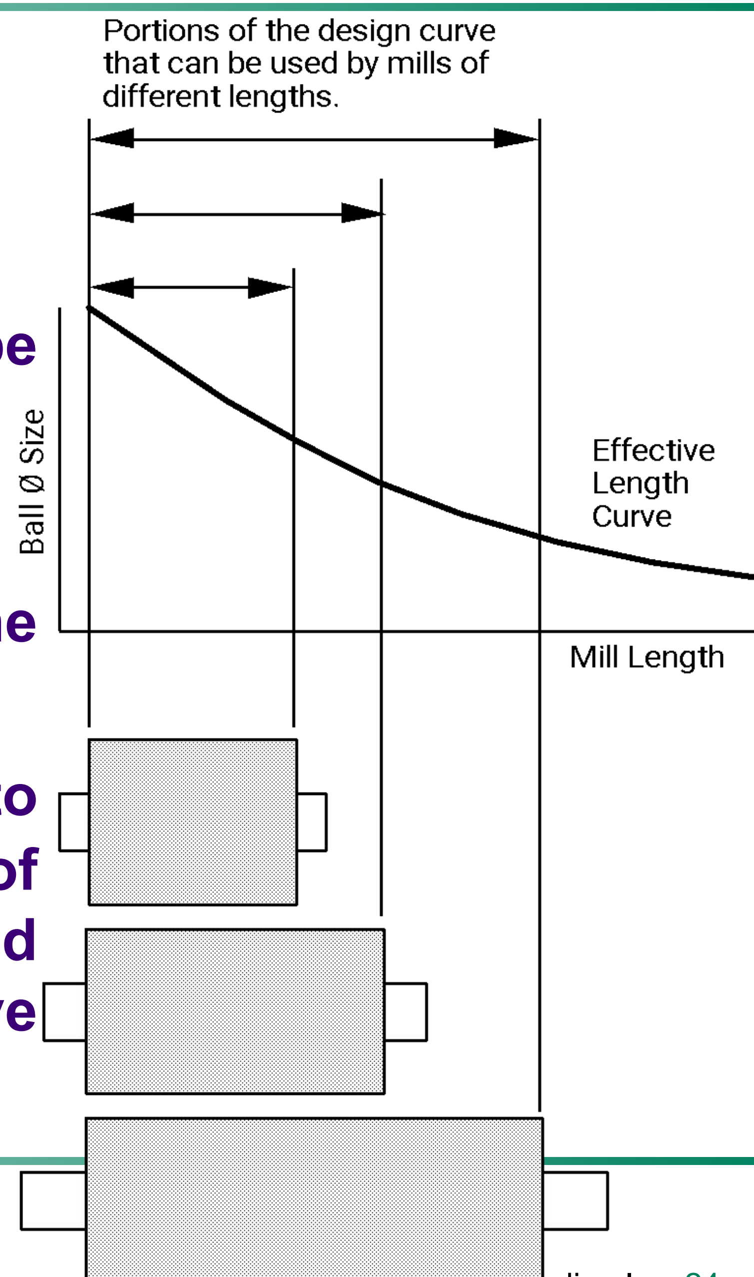
Effective length curves

- Convert the % weight to equivalent % length
- Plot effective mill length vs. ball Ø



Why use a curve?

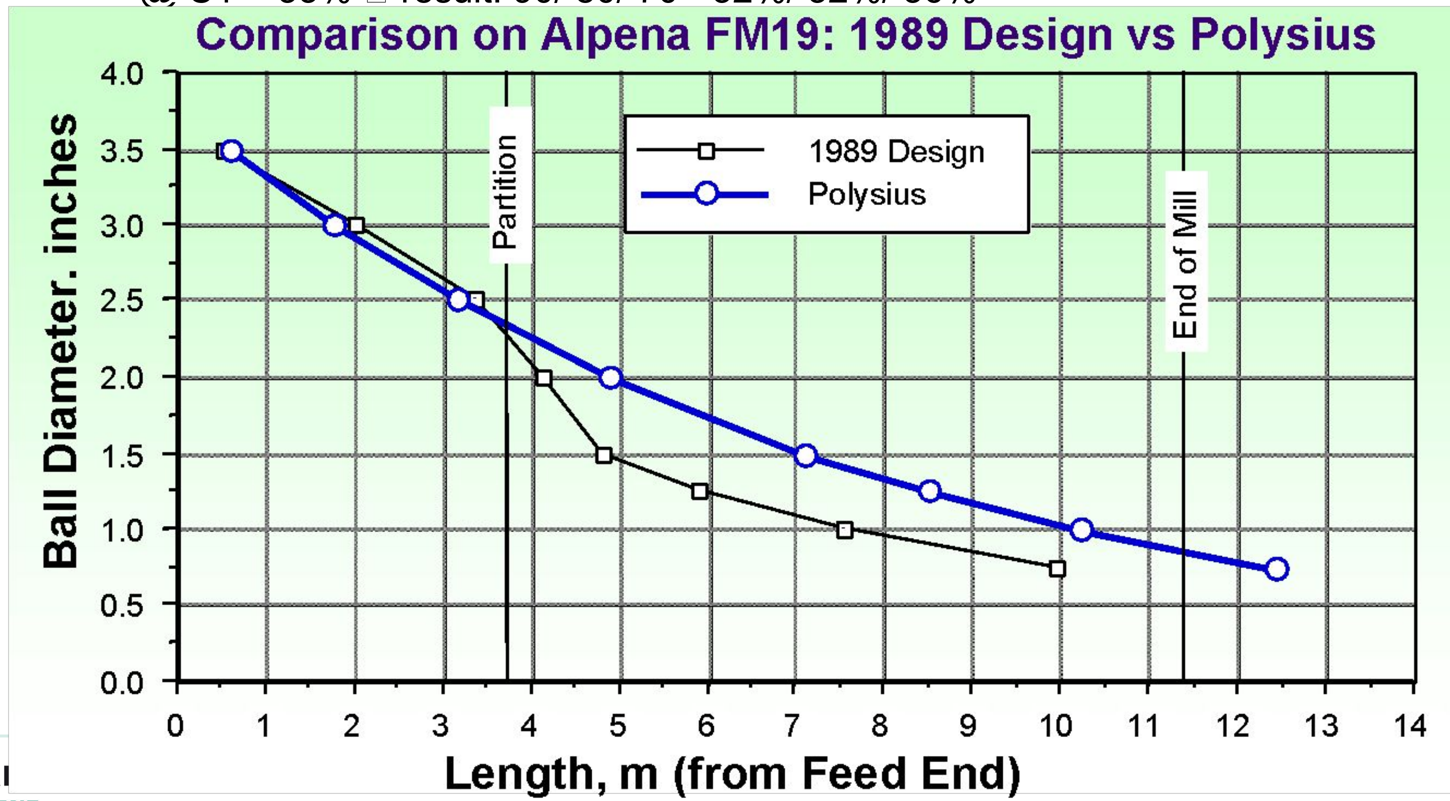
- **Only so much grinding can be done over a given length of mill**
- **Must match particle size to ball Ø**
- **Therefore the longer the mill, the smaller ball Ø it can use**
- **Smaller particles get harder to grind, thus we must use more of the smaller sizes to maintain good grinding. This results in a curve instead of a straight line**



LAFARGE CEMENT
EUROPE TECHNICAL CENTER

Polysius design

- **Use exponential curve**
  - Start with 90mm top size
  - Result depends on compartment length
  - @ C1 = 33% □ result: 90/ 80/ 70 - 32%/ 32%/ 36%



Slegten Model

- **Divides the mill into 3 parts**
  - **Preparation** in the 1st Compartment
    - Same quantity of 80, 70, 60mm ∅ balls 16% of 60mm ∅
    - Addition of 90 mm ∅
  - **Transition** zone in the 2^{nd} Compartment
    - Same quantity of 50 and 40 mm ∅ balls
  - **Finishing** zone in the 2^{nd} Compartment
    - 30, 25, 20 and 17 mm ∅ balls (for example)
    - Exponential function: $\varnothing(cm) = 3{,}3\ .e^{(-0{,}1\ .\ X)}$

      (x = effective length in m)
    - Effective length curve with origin at the partition wall

LAFARGE CEMENT

EUROPE TECHNICAL CENTER

Slegten Model

First Compartment

∅ Ball (mm)	% of Weight (x)	% of Weight	Number of Balls
90	100 – 5x	20,0%	
80	2 ,4x	38,4%	N
70	1,6x	25,6%	N
60	x	16,0%	N

Usually (x) is taken at 16,0%

Second Compartment

Transition Zone

∅ Ball (mm)	Number of Balls
50	N
40	N

Finishing Zone

- $\varnothing(cm) = 3{,}3\ .e^{(-0{,}1\ .\ X)}$

  (x = effective length in m)
- Effective length curve with origin at the partition wall

Slegten model example calculation

- **Material characteristics**
  - Clinker
  - D80 = 15 mm
  - Wi = 13,49 kWh/t
  - ρ = 3,09 g/cm^3

Slegten model example calculation

- **Closed circuit cement mill**
  - L/D = 3
  - Du = 3,65 m
  - Lu = 10,95 m
  - Useful length C1 = 3,28 m (30%)
  - Useful length C2 = 7,67 m (70%)

  - Mill speed = 75% of critical speed (16,6 rpm)
  - Ball charge bulk density C1 = 4.5 t/m^3 C2 = 4.7 t/m^3
  - Steel density = 7.8 t/m^3

  - Volume loading C1 = 30%
  - Volume loading C2 = 28%

Excercise

- **Calculate biggest ball**
  - Remember

$$\text{Ø}max = 20{,}17 \,.\, \sqrt{\frac{D_{20}}{K}} \; \sqrt[3]{\frac{Wi.\rho}{\%Vc.\sqrt{Du}}}$$

- **Propose a ball charge (Slegten)**

LAFARGE CEMENT
EUROPE TECHNICAL CENTER

Ball charge optimization (existing mill)

- **Calculate theoretical ball charge as a reference**
- **Perform a mill audit to assess critical points**
  - Axial test: grinding efficiency of the charge, presence of nibs…
  - Partition condition: slot width, broken plates…
  - Condition of ball charge and liners
  - Coating, temperature, water injection…
- **Adjust ball charge according to conclusions**

When several products are made with the same mill, check conditions for all of them

Ball charge management

- **Having a well-designed ball charge is one thing…**
  … but you need to keep it this way in time
  - Wear
  - Balls can break, lose their shape
  - Pollution by foreign bodies
  - Partition liners can break balls get mixed
- **Object of ball charge management**
  - Top-ups
  - Ball charge sorting
  - Wear calculation

Top-ups

- **Follow-up at least every month**
  - Check mill power consumption (same product every time)
  - Free height measurement on purged mill
- **Top-up decision**
  - Ratio should be known
    - 10 kW ~ 1 t of balls
    - Or 1% filling level ~ x t of balls
  - Rules to be established for each plant: when to add balls
  - Usually add only bigger balls
- **Methods**
  - Mill stopped: through doors
  - Mill in operation: through inlet trunnion (possible with feed, but not recommended)
  - Always record date, ball size and quality, weight…

Ball charge sorting

- **Objective**
  - Eliminate scrap, broken and undersize balls
    - scrap = foreign metallic elements polluting the ball charge (bolts, pieces of liners, …)
  - Go back to optimal ball charge
- **Minimal frequency**
  - C1
    - Every year or 7500 to 8000 hours
  - C2 (and C3)
    - Every 2 years or 15000 to 16000 hours
  - More often when necessary (very high wear, wet mills…)

Sorting method

- **Purge mill, take everything out of the compartment**
- **Sort, weigh and record**
  - By size classes for still usable balls (ex: 75 – 85 mm = 80 mm class)
  - Undersized balls (not suitable for the compartment)
  - Broken, out-of-shape balls (not reusable)
  - Scrap
- **Sorting machine recommended**
- **When a plant has several mills, it can be easier to have an extra charge ready to put in the mill gives more time for sorting**

Wear calculation

- **Can be done only if proper records of charges, top-ups and sorting are kept**
- **Major indicator = wear rate in g of metal / ton of product**
  - By compartment or globally
  - Count only worn metal from balls (not scrap)
- **Other indicators can be calculated if specific needs**
- **Example**