Ball Mill Dynamics

GRINDING I – Training Session

Content

- Size reduction mechanism
- Release point and internal dynamics 1st and 2nd chamber
- 1st chamber liners
- 2nd chamber liners
- Fastening types
- Balls
- Mill head liners
- Material transport

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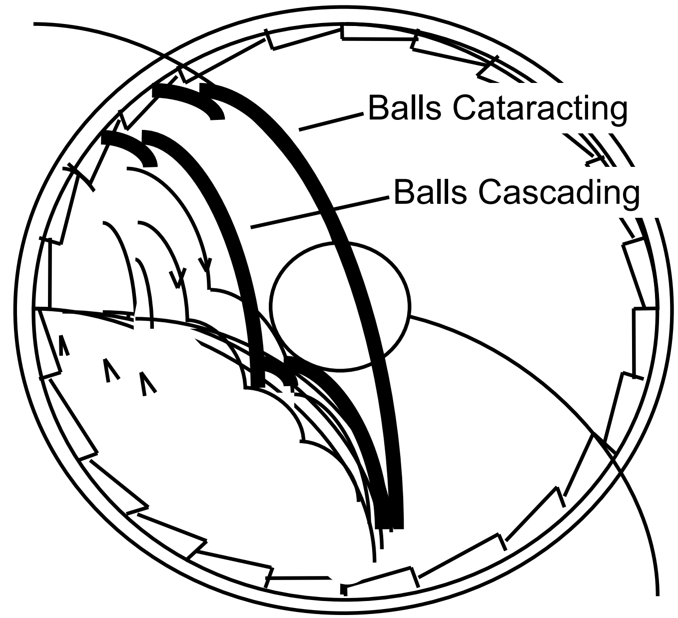
3 mechanisms of size reduction

- **Fractures**
  - Crushing
- **Chipping**
  - Crushing and some fines
- **Abrasion**
  - Fine grinding

Internal ball dynamics

- **Cataracting**
  - Free fall of the balls
  - Emphasis on crushing
- **Cascading**
  - Tumbles along charge surface
  - Emphasis on fine grinding



Internal dynamics depends on the release point

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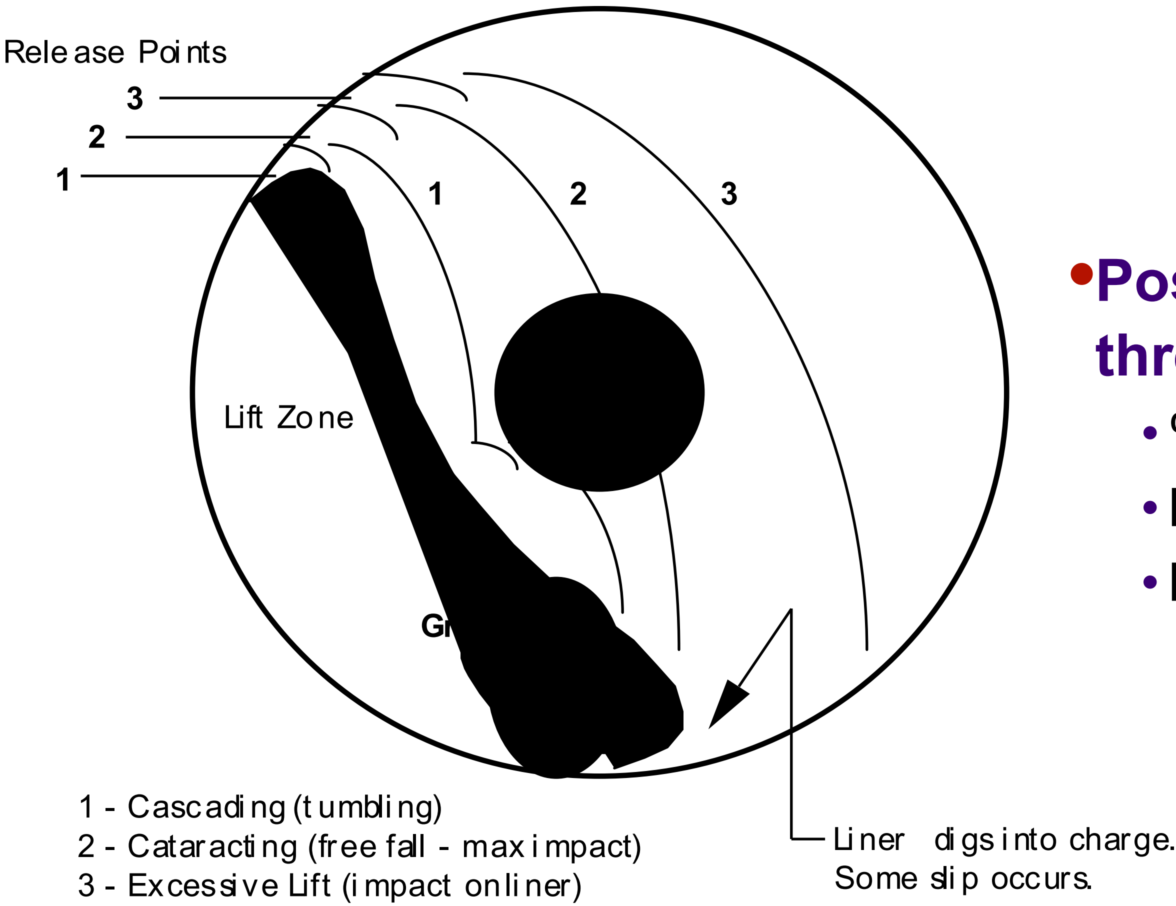
Release points and grinding



- **Position depends on three main factors**
  - % of critical speed
  - Liner's design
  - Ball filling rate

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Release point and mill critical speed

- **Speed of rotation at which centrifugal forces overcome gravity forces**
  - At that speed, the balls no longer fall or cascade but ride on the liners around a full revolution

$$n_c = 42.3 / \sqrt{D}$$

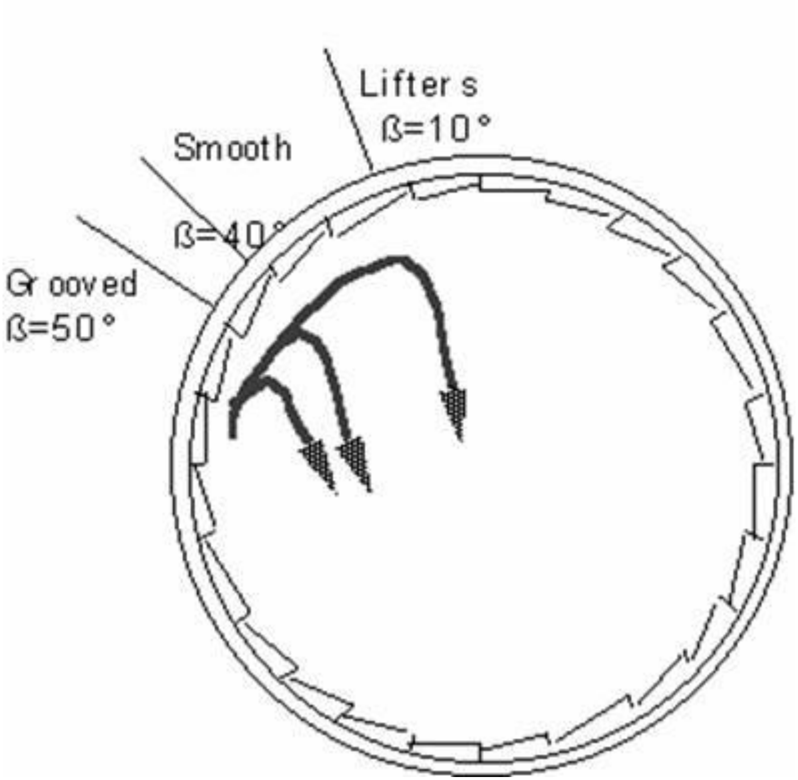
- **The best grinding efficiency is reached at 75% of the critical speed**

$$n_{opt} = 32 / \sqrt{D}$$

- **Mill speed is usually between 70 to 78% of n_c**

Release points and liners design

- **Different liners design can give different release points and therefore different grinding actions**

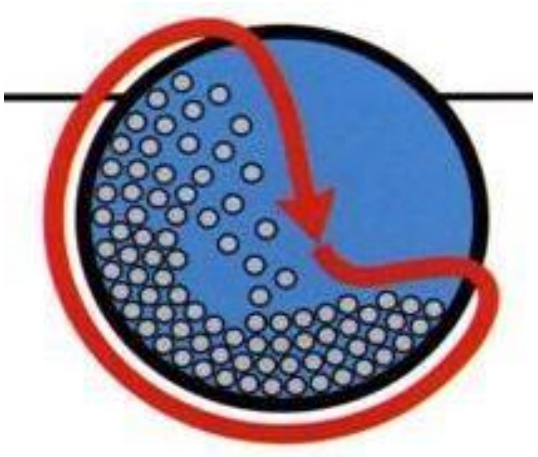


Internal dynamics in first chamber

- **Primary grinding of coarse material with large grinding media (Ø 90-60 mm)**

- **Aim: high activation of the ball charge for CRUSHING action**

- **Good efficiency criteria**
  - Before intermediate diaphragm:
    - 5% of rejects at 2.5 mm
    - 15 to 25% of rejects at 0.5mm



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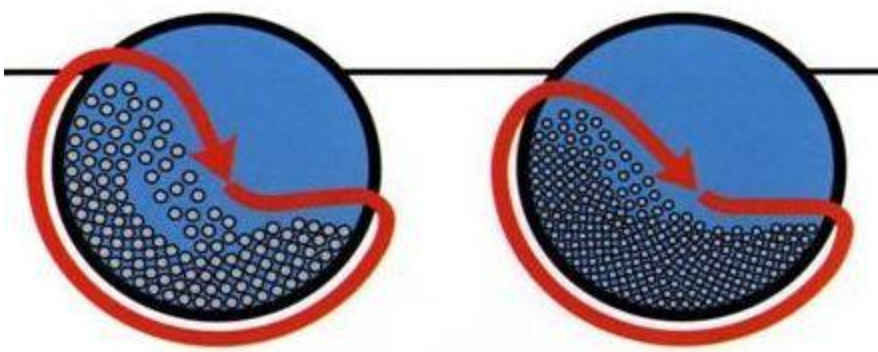
Internal dynamics in second chamber

- **Development of a high fineness with small grinding media (Ø 50-15 mm)**
- **Aim: ATTRITION and PRESSURE grinding**
- **Good efficiency criteria**
  - Before discharge diaphragm
    - 5% of rejects at 0.5 mm
    - 20 to 30% of rejects at 0.2mm



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Purpose of a liner’s design

- **Each liner is designed to ensure:**
  - Lowest specific energy consumption
  - Highest production capacity for a shell design
- **Protect mill shell and ensure efficient grinding action**
- **With lowest possible specific cost for liners**

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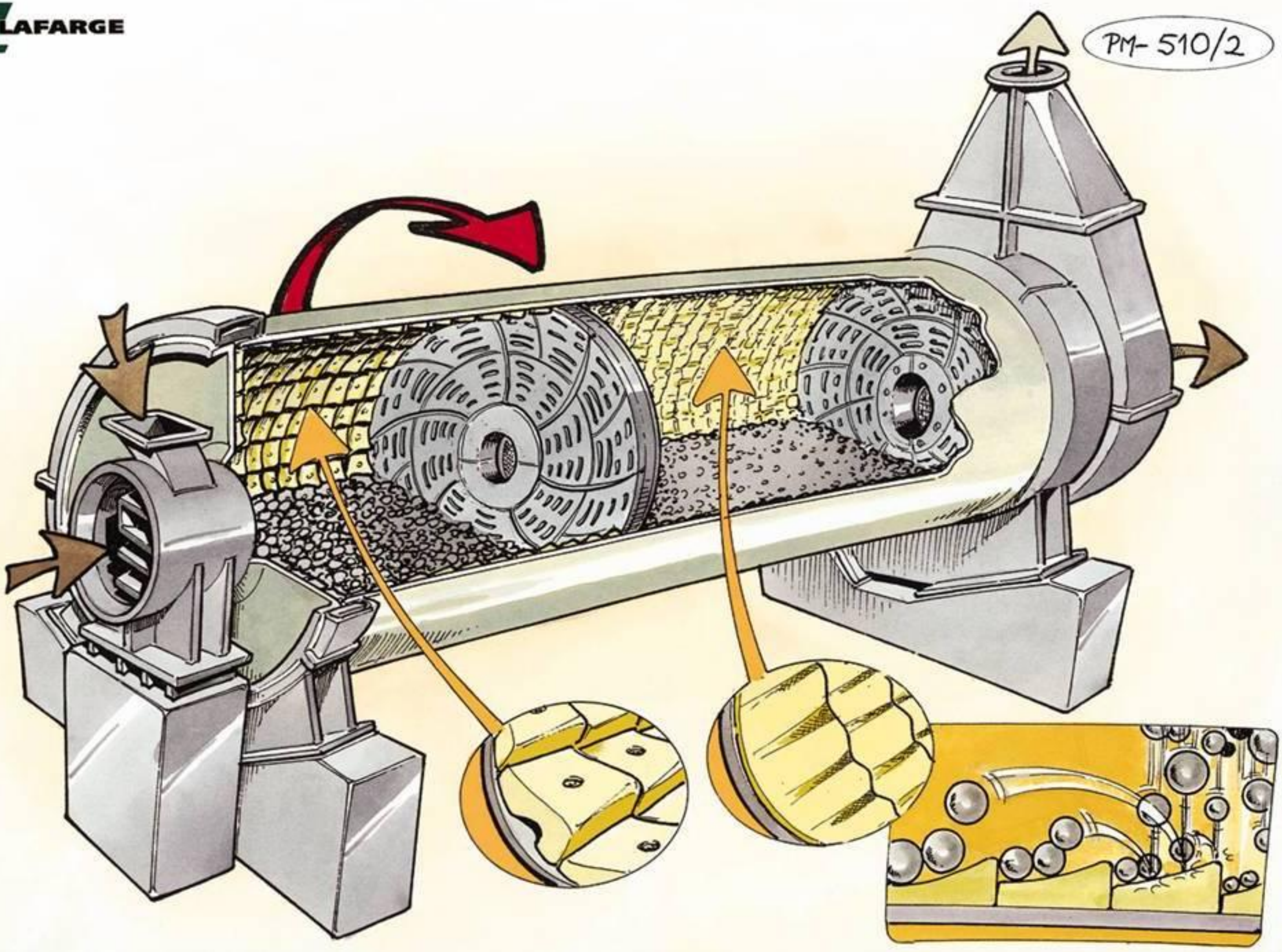
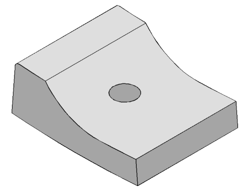
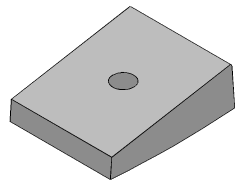


First chamber liners

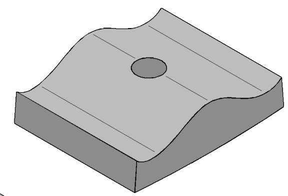
- **Activator liners**



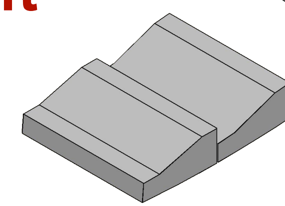
- **Step liner**



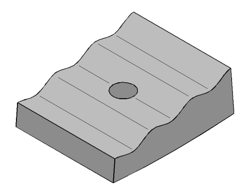
- **Wave liner type “Duolift”**



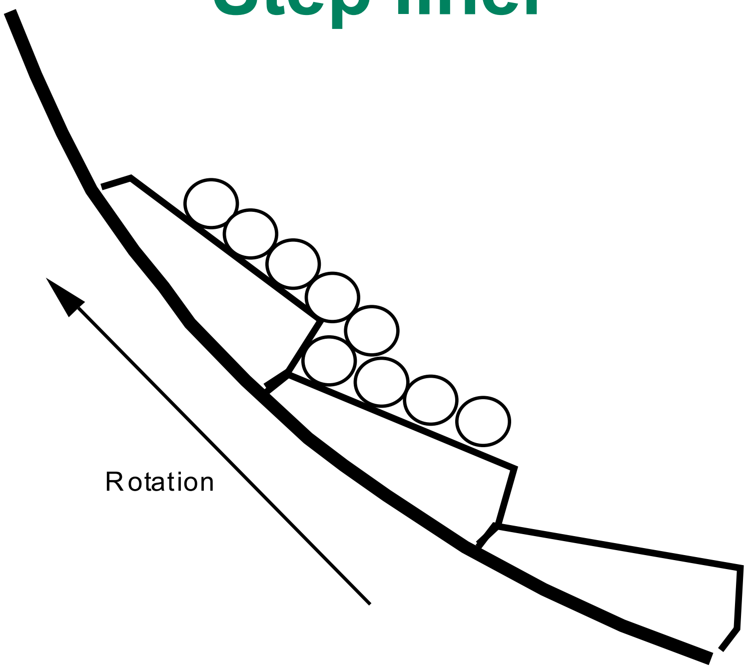
- **Step liner tpe “Xlift”**



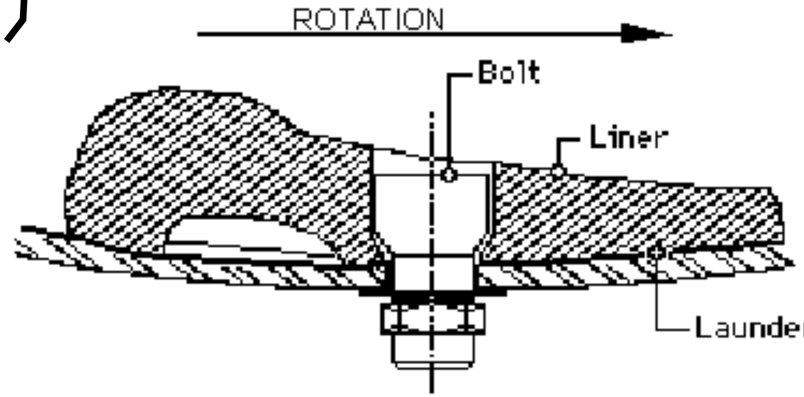
- **Step liner with wave profile**



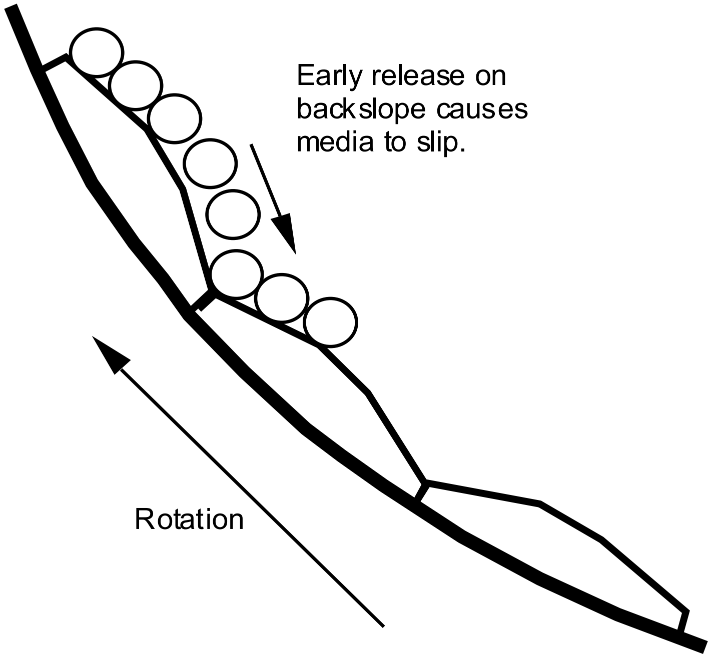
Step liner



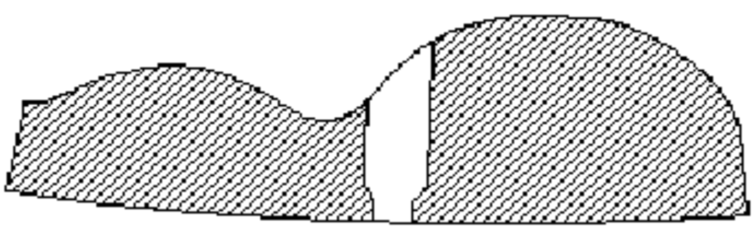
- Only for first compartments
- Better wear characteristics
- Moderate lift
- Designed for DIN drilled shell



Single wave & Duolift liners



- **Only for first compartments**
- **Single wave**
  - Negative back slope induces sliding
  - Racing is common, wear life is short
  - It has good lift
- **Duolift**
  - Has a small hump in between lifts to prevent racing
  - Liner's life is much better



Slegten DUOLIFT Liner Profile

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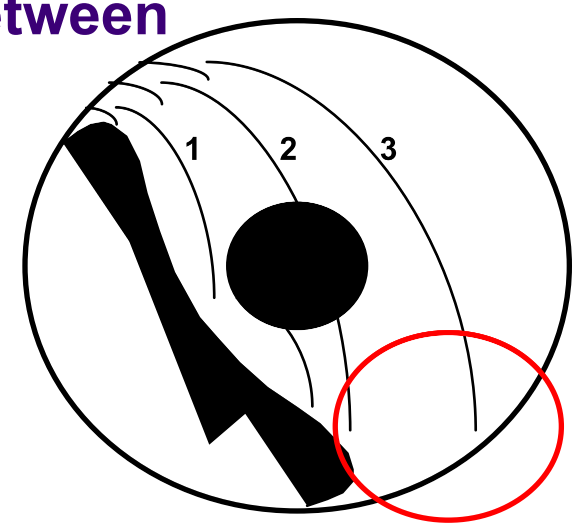
Installed Duolift liners

First chamber - Reminders

- **Be careful of the appropriate ratio between**
  - Critical speed
  - Liner lifting action
  - Ball filling rate
  - Ball size

    Risk of broken liners or high wear level



- **Liners must be changed when 60% of their effective lifting height has worn away**
  - Consequence 8 to 10% production loss

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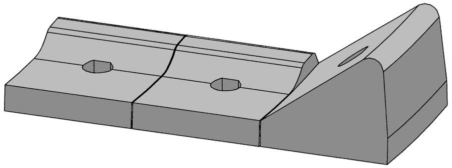
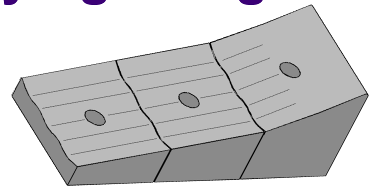
Second chamber liners

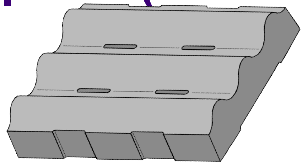
- Classifying lining with activator profile



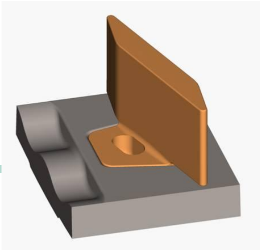
- Conventional classifying lining with wave profile



- Wave lining type “Dragpeb” (without classifying effect)



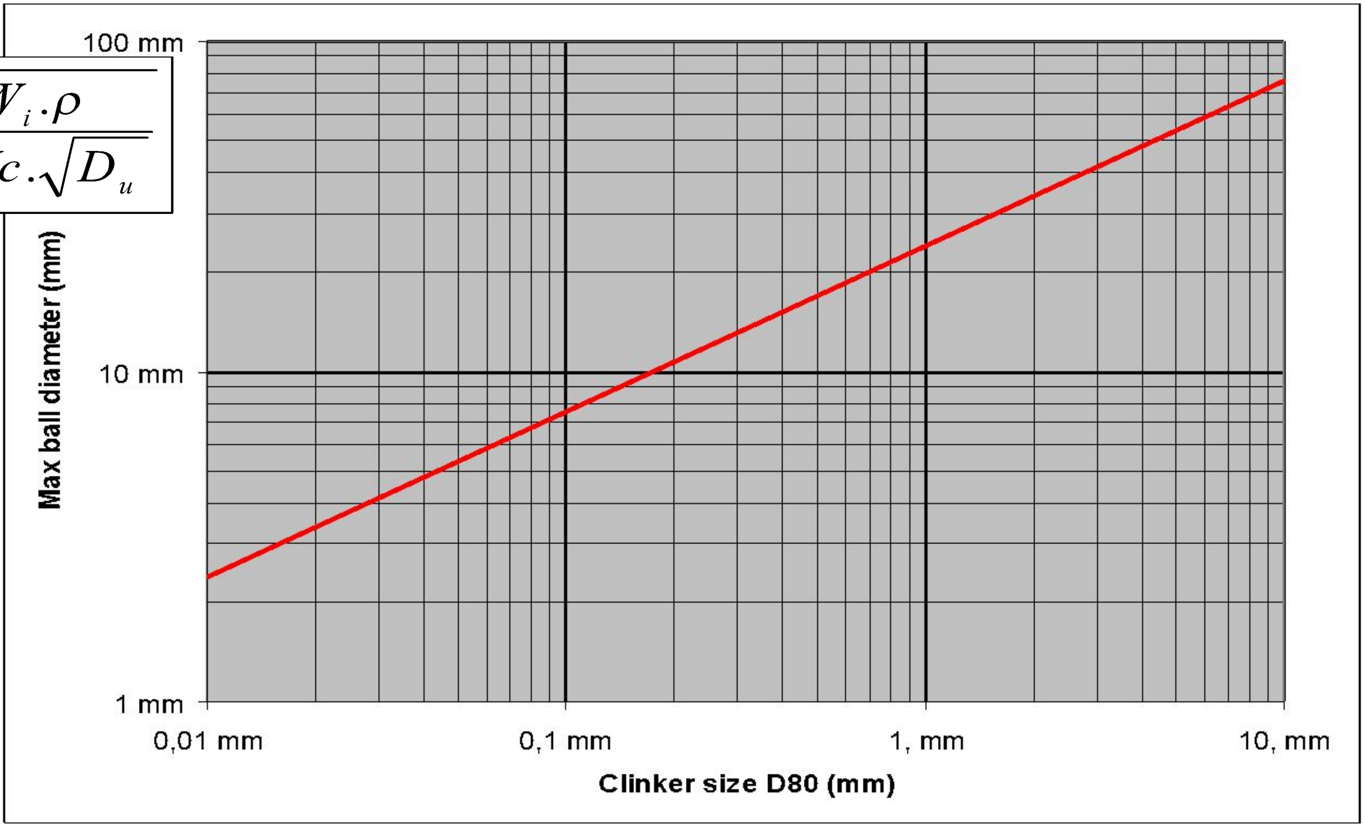
- X-Class



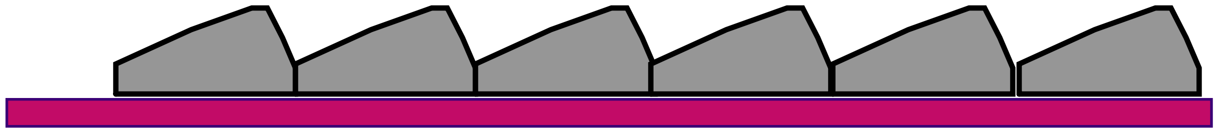
Purpose of classifying liners

- Match ball size to particle size (Bond Formula) without partitions

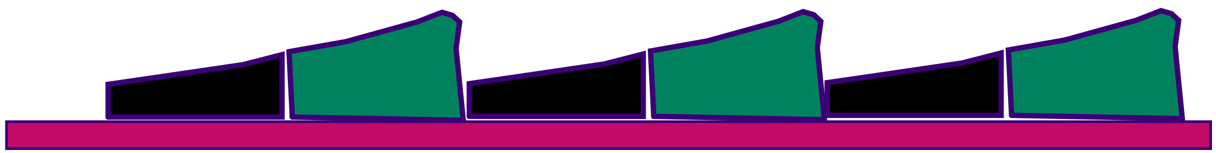
$$d_{max} = 20.17\sqrt{\frac{d_{20}}{K}}\sqrt[3]{\frac{W_i.\rho}{\%Vc.\sqrt{D_u}}}$$



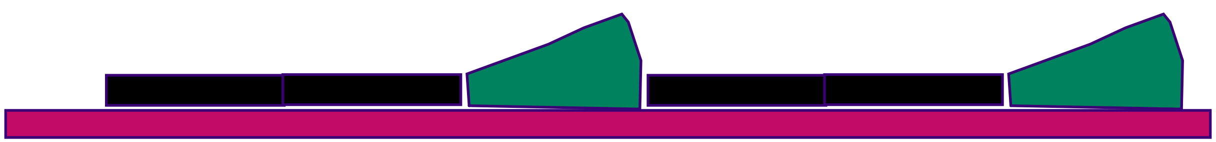
Examples of classifying liners



CARMAN LINING



SLEGTEN - MAGOTTEAUX TYPE



NATAL (THIN PROFILE TYPE)

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Classifying liners - issues

- **Causes of poor classification**
  - Liner's step wear
  - Lifting of the charge too low
    - wave-like wear profile
  - Ball filling ratio > 35%
  - Nibs in the charge
  - Overfilling of the compartment
    - circulating load to high
    - Coating

- **If no classifying liners**
  - $D_{max} / D_{min} < 2$

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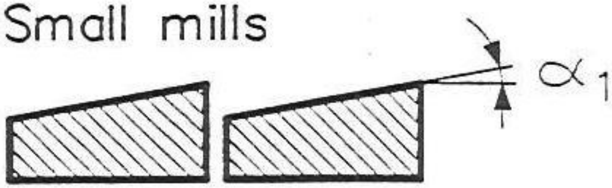
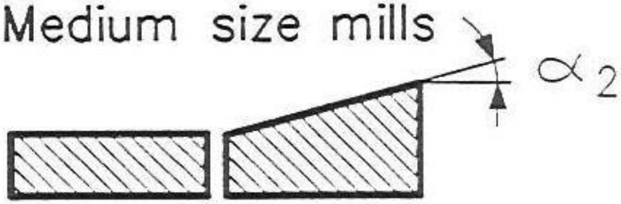
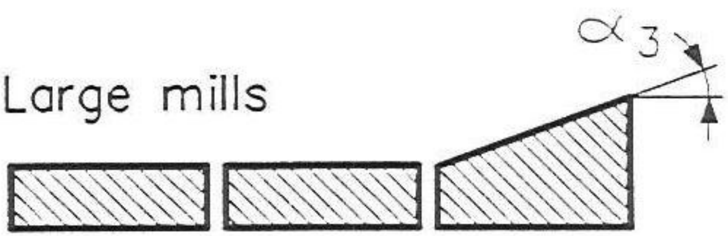
Classifying liner design and mill shell size

	Mill shell diamet
Small mills 	**Ø < 3 meters**
Medium size mills 	**3 m< Ø < 4 m**
Large mills 	**Ø > 4 m**

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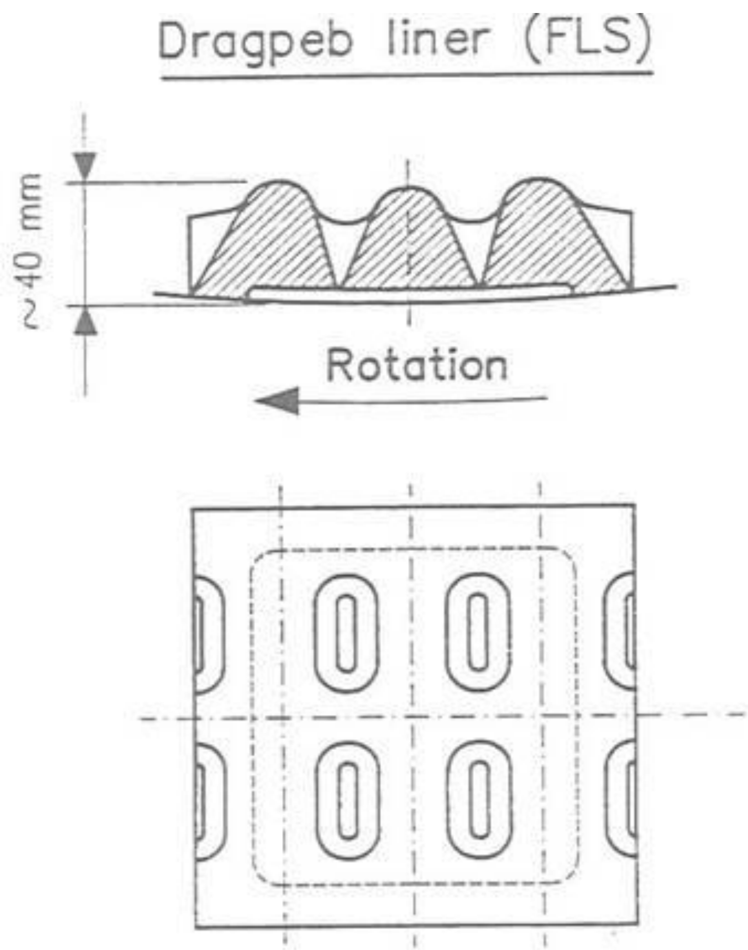
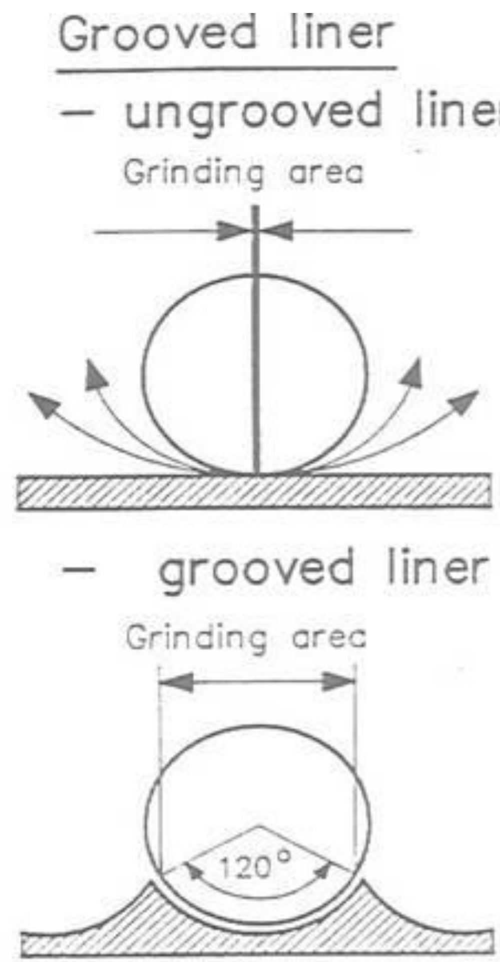
Other types of liners : grooved liners





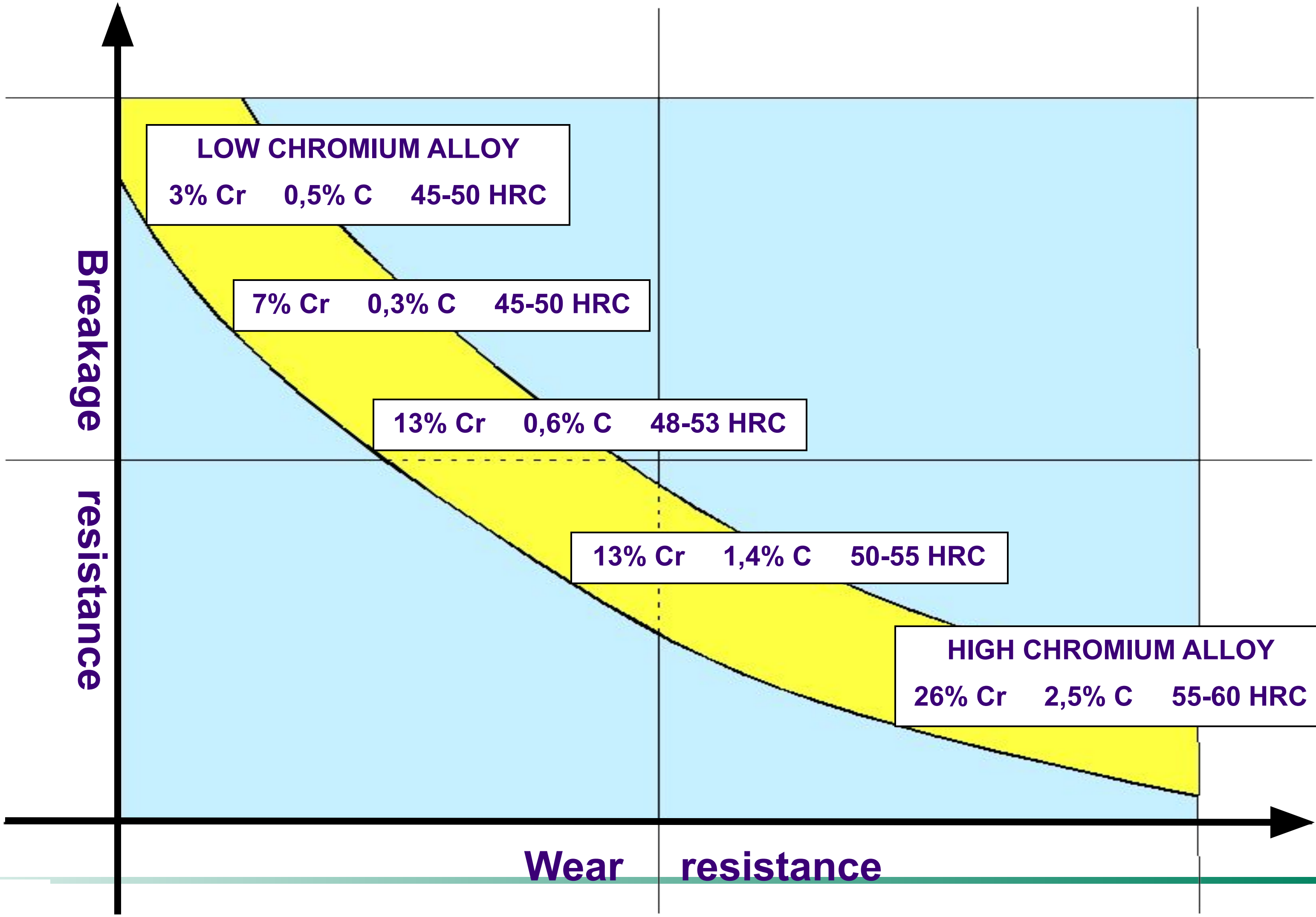
Other types of liners : Danula or Dam Rings

- **Where we find it**
  - Long mills, in the second chamber
- **Role**
  - Keep the grinding media in the same location
- **Disadvantages**
  - Lagging material transport in the mill
  - Balls must be charged in a specific order to ensure proper ball distribution

Second chamber - Reminders

- **Classifying liners**
  - Causes for poor classification
    - Liner step wear
    - Lifting of the charge too low
      - Liner wave wear
    - Ball filling ratio > 35%
    - Nibs in the charge
    - Overfilling of the compartment
      - Circulating load too high
      - Coating
- **Without classifying liners**
  - $D_{max} / D_{min} < 2$

Liner material selection:



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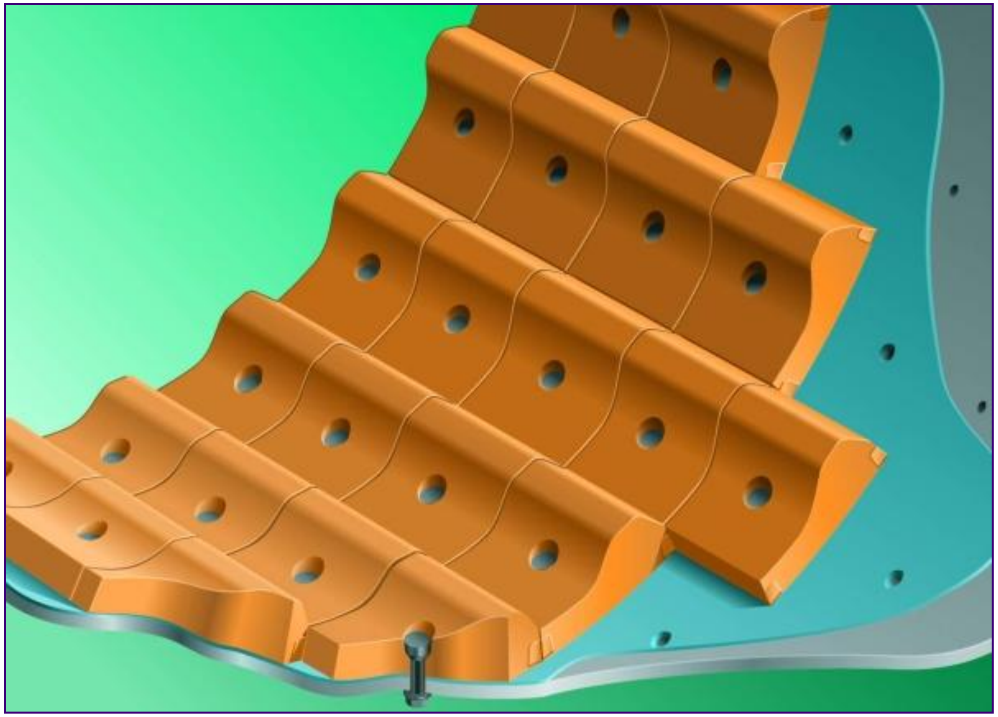
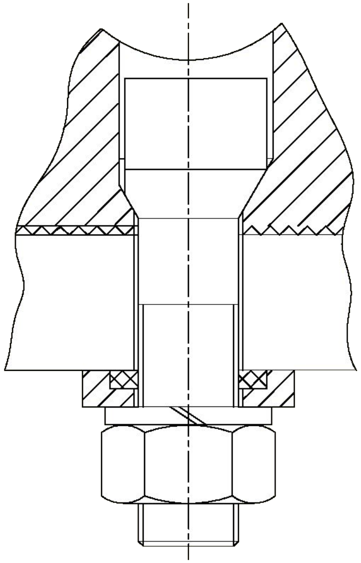
Fastening types

- **Bolted**





- Requires a drilling in the mill tube for every plate
- Easy handling during installation and maintenance

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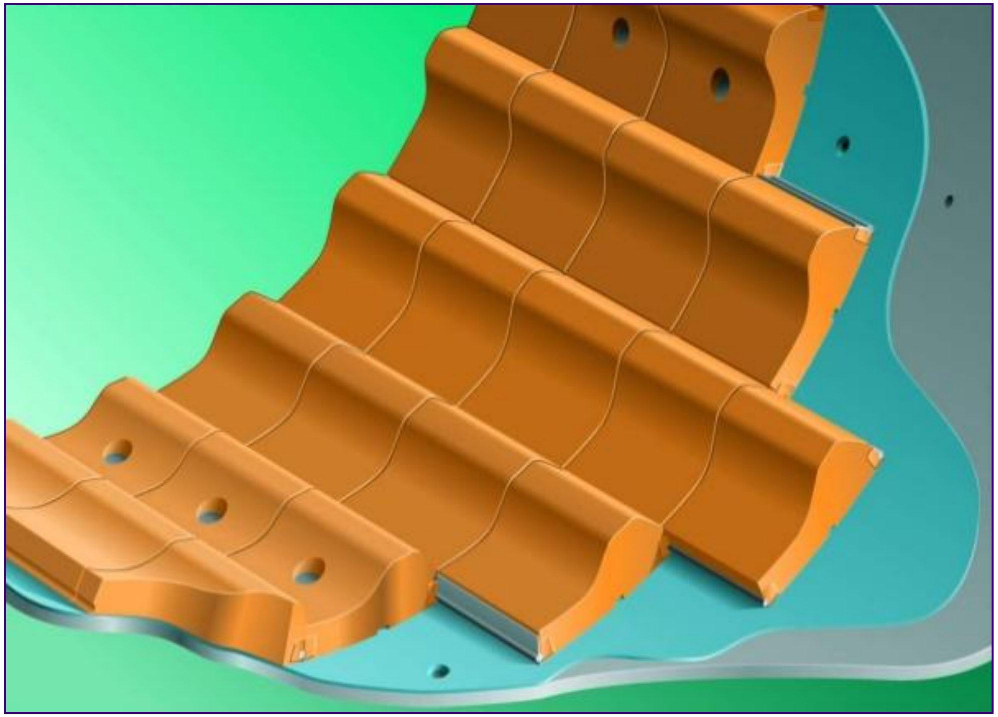
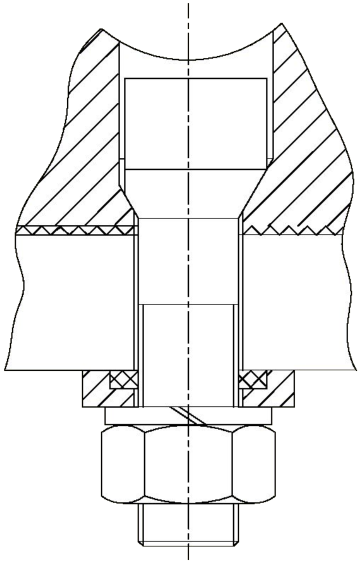
Fastening types

- **Semi-bolted**

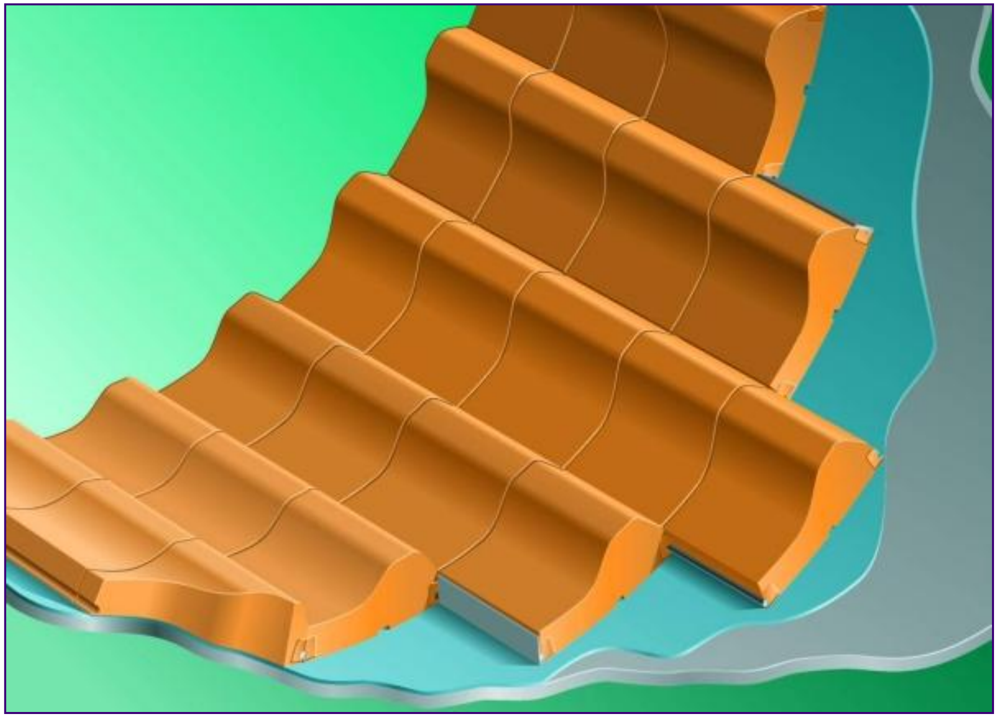


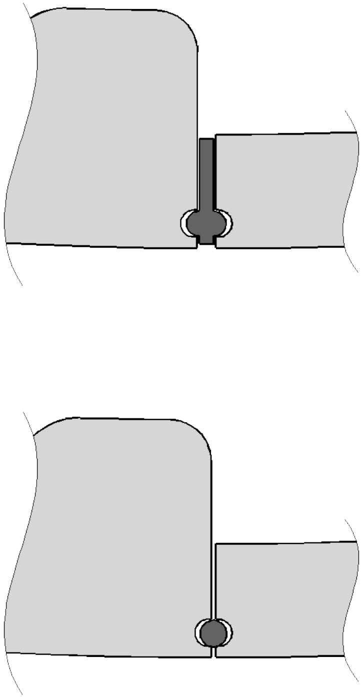


- Minimum two bolted rows in total
- Requires special tools and experienced fitters

Fastening types

- **Boltless**





- Plates are forced-fitted with positive locking without any bolts
- Requires precise preparation, special tools and very experienced fitters

Liners’ wear management

- **Liner wear optimisation**
  - Avoid metal / metal contact
    - Minimise purge duration
    - Look for optimal material filling rate
- **Bolt holes can result in casting flaws: failures occur there first.**
- **Boltless liners wear better, but require careful installation**

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Balls wear

WEAR RATE *FIRST AND SECOND COMPARTMENT*	g/t
Portland Cement 96% Clinker + 4% Gypsum (3000 Blaine) as well as a typical raw material	20-45
Portland Cement 96% Clinker + 4% Gypsum (4500 Blaine)	25-50
Cement with 25 to 30% slag or trass (4500 Blaine)	40-60
Cement with ± 70% slag (3000 Blaine)	50-75
Cement with ± 70% slag (4500 Blaine)	70-95

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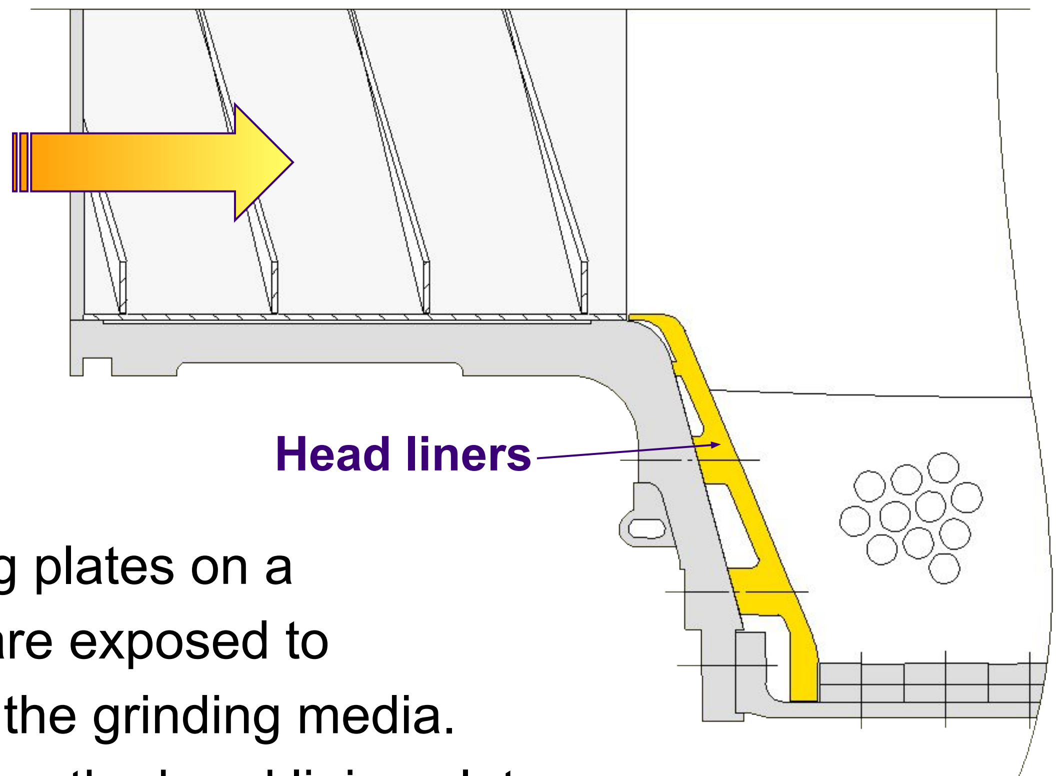
Mill head lining

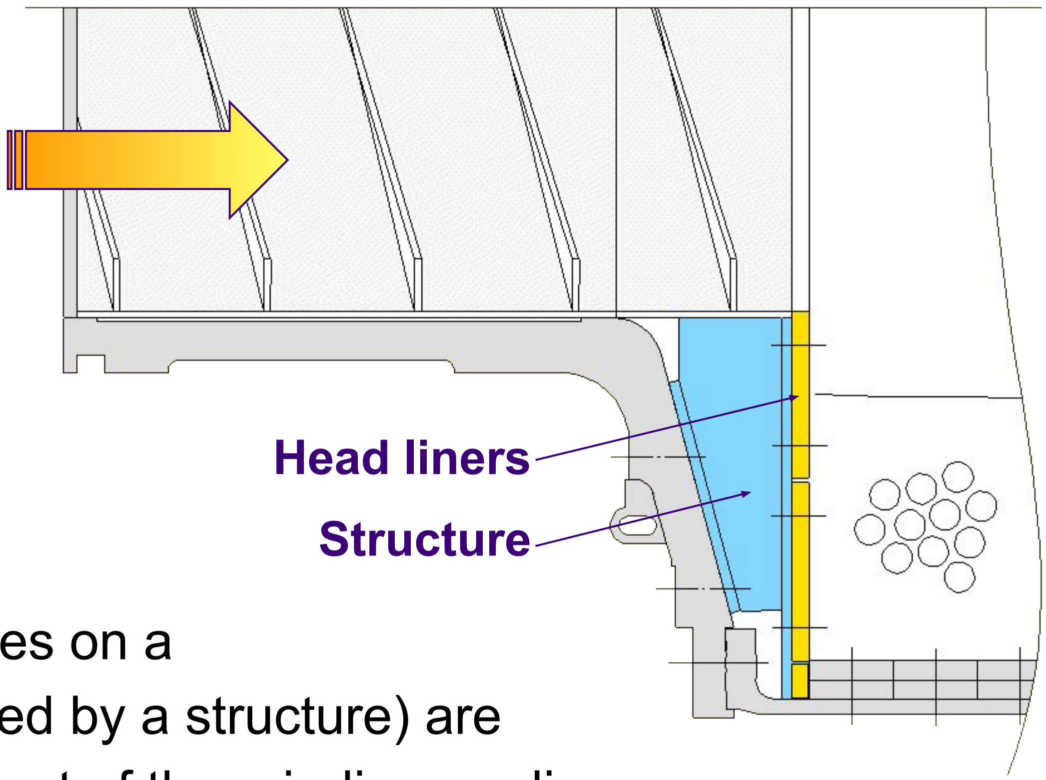
- **Conical design**



- Conical head lining plates on a conical mill head are exposed to the high impact of the grinding media.
- Result: high wear on the head lining plates

Mill head lining

- **Straight design (with structure)**



- Straight head lining plates on a conical mill head (realized by a structure) are protected from high impact of the grinding media.
- Result: less wear on the head lining plates

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Mass transport

- **Reason for mass transport in the mill shell**
  - Mill inlet feed pushes the material ahead
  - Mill sweeping
  - Pumping actions of the partition and discharge wall
- **The mill retention time is about 10 to 15 minutes in closed circuit**
  (20-30 min in open circuit)

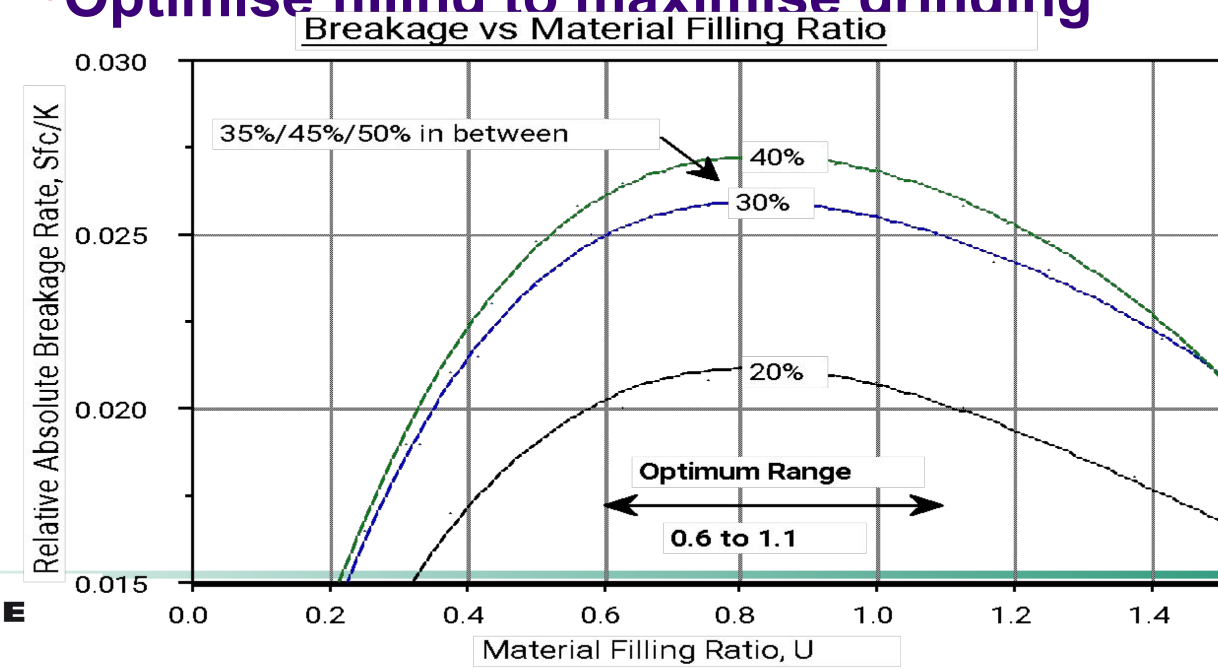
Material filling ratio

- **Definition**

$$\text{Material filling ratio} = \frac{\text{volume of material}}{\text{volume of voids in the charge}}$$

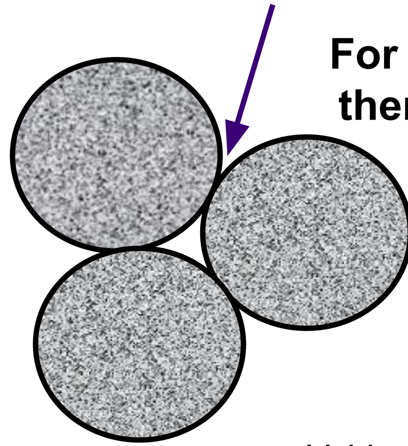
(In practice, it is evaluated with the level of material above or below the charge surface)

- **Optimise filling to maximise grinding**

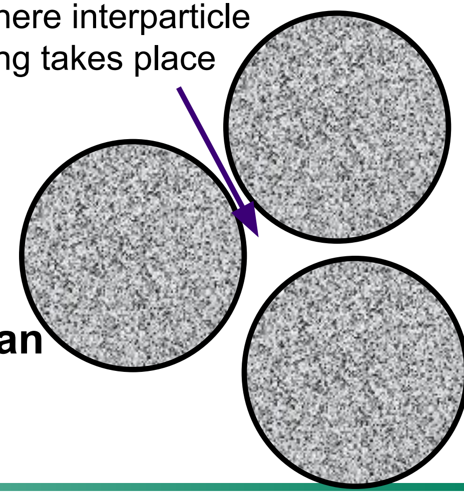


Grinding vs. filling

- Interparticle grinding occurs when the voids space is properly filled
- The collision of balls causes momentary high pressure compression



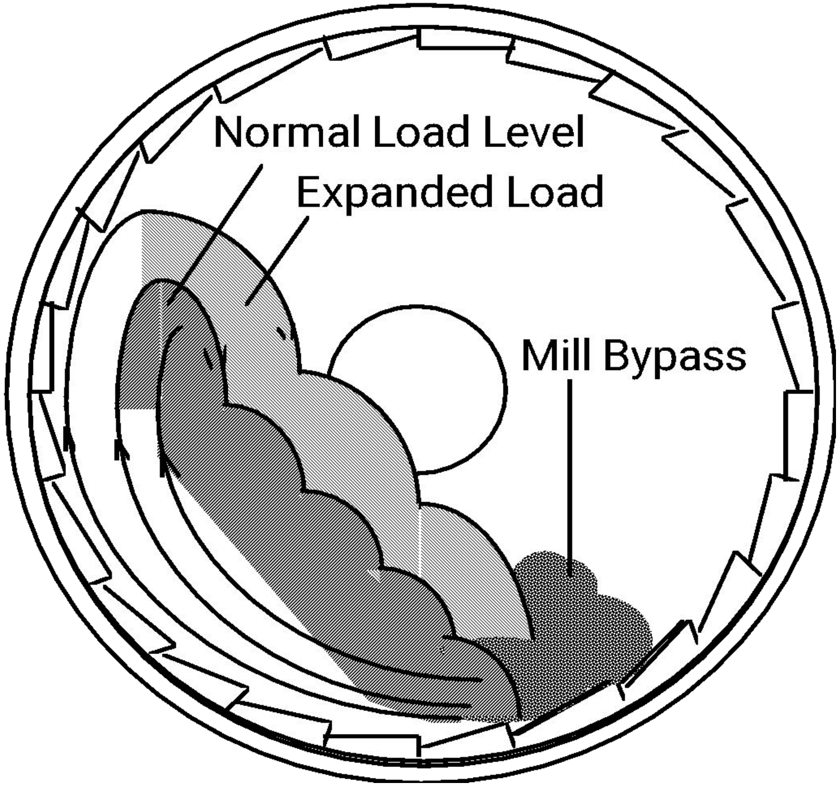
For filling ratios less than 0.6 there's steel to steel contact and no grinding



For filling ratios greater than 1,1 balls are pushed apart, cushioning impact

Mill bypass

- **Ball charge expands when overloaded**
- **In the extreme, a stream of material "bypass" the load at his toe**
- **Consequences**
  - Chips and spitzers will accumulate at the discharge end
  - Once past a critical point, production drops off



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How to manage the material filling rate

- **Ball charge design**
  - The charge permeability depends on ball size
- **Circulating load level**
- **Tuning of the partition drain effect**