EIT Innovation Days
BASF UGC Mine Backfill
Ludwigshafen, Sep 2018

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Global Technical Manager Mine Backfill

Ludwigshafen, 14.09.2018
BASF provides Chemicals and solutions for:

- Construction work
- Rock support (operation)
  - Sprayed concrete
  - Injection
  - Anchoring
  - Backfill
- Mineral processing and
- Tailings disposal (with backfill it presents total tailings management solution – unique in the industry)
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General
- Backfill in the mine cycle
- Who benefits from backfill
- Why discussing?

Backfill
- Types of backfill
- BF objectives
- Concept and mix design

Backfill admixtures
- Types
- How they work
- Effects
- Benefits

Testing
- Concept and Targets
- Lab demonstration
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Backfill project & economics
- Economics
- Results/Achievements/Value
Filing mine cavities with some material or materials in the aim to establish and retain safe working conditions economically - is called backfill. Materials range from rock gravel, quarried sands and to tailings left over from the removal of the valuable minerals from the ore.

Backfill in general could be divided into two groups:
- Uncemented
- Cemented

There are few main types of cemented backfill:
- Cemented Rock/Aggregate backfill (CRF/CAF)
- Cemented Hydraulic backfill (CHF)
- Cemented Paste backfill (CPF)
- Composite Aggregate Paste (CAP)
Cut and fill method

The main purpose of the backfill in this mining method is to provide a working platform for miners and equipment but is often also a method of supporting the stope walls.

Undercut and fill method

This mining method is most commonly used in areas of very high stress to minimize the effects of rockbursting. Backfill is extremely important with this mining method, as the backfill mass becomes the roof under which the miners and equipment are working.
Two types of Cut&Fill

Overhand
- Backfill becomes working platform for miners and equipment
- Enough strength to support heavy equipment

Underhand
- The backfill becomes the roof under which the miners operate
- Mainly used in high stress areas (avoid rock bursting)
Vertical crater and retreat method (Stope)

An open stope requires that a barricade be constructed at the draw-point and backfill is introduced into the top of the stope.

Room and pillar method

The room-and-pillar mining method is commonly used in flat-dipping ore bodies that have a large plan view area. It allows for mining to progress in two directions leaving pillars to support the roof. Many mines want to recover the ore that is left in the pillars and this is where backfill comes into use.
Total Mining cycle – sustainable approach

- Above ground
  - Mineral processing
  - Concentration
  - Tailings Management and Backfill

- Underground
  - Mining
  - Excavation
  - Backfill
Backfill operation

Include:

- Thickened and filtered tailings (floccs)
- Mixing with cement
- Pumping or gravity transportation
- Placing and consolidation (hardening)
- Cable bolting and grouts (for barricades frames fixation)
- Sprayed concrete (barricades construction)

**Backfill operation itself is already full UGC sector approach!**
Why discussing, educating and training people in backfill

1. Backfill is representing 25-30% of total mining cost
2. Binder is 70% of backfill cost, but benefits can be related to the other values
3. Operational limitation and maintenance/blockages can become hot operational issue (BF became a bottleneck and/or important cost issue). Total mining cost and mining production influenced
4. Once mining cycle well established backfill become first mining operation: “First you backfill than you mine”
5. Often limitation in expanding mine production related to the backfill capacity or production limitations Very often wrongfully not understood and appreciated “Spending money”
6. Very often with limited recourses and budget, shared recourses but with high expectations
Who benefit from Backfill?

**Governmental authority**
- Responsible for legislation
- Licensing and implementation
- Monitoring of technical solutions

**Company Headquarter**
- Improve profitability
- Zero loss time due to injury
- Environmentally friendly impact
- Reduce water & carbon footprint (eco efficiency)
- Reduce the capital cost needed to get to the target (production targets)
- Use a model in other mines

**Underground Mine**
- Faster stope filling
- Enhance water management
- Faster reentry
- Responsible for overall safety
- Faster decantation
- Reduction in fill dilution

**Backfill plant**
- Decrease in binder content
- Increase in fill density with same transportability
- Reduce maintenance cost and downtime
- Overall saving for the operation with increased efficiency
- Higher production and filling rate - lower cost
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Backfill Types

- **Cemented Rock Fill**: Generally consists of waste rock mixed with a cement slurry to improve the bond strength between the rock fragments. Methods of placement include mixing rock and slurry in a hopper, bucket or truck box, and percolating slurry over previously placed aggregate.

- **Hydraulic Sand Fill**: Hydraulic sandfill consists of either classified mill tailings or naturally occurring sand deposits mined on surface. The fill is placed in the stopes through a series of pipes and boreholes from the backfill plant on surface. Hydraulic fills are considered a low density backfill and are generally placed at a range of 40% to 70% solids which involves a significant amount of water to aid in transportation.

- **Paste Fill**: Past backfills are considered to be high density backfills which are placed at a 70%+ solids. Whole mill tailings are often used to make paste backfill (condition minimum 15% -20 microns). Advantages to using paste fills include low water requirements, lower binder requirements, minimal barricade construction, reduced water pumping to surface, and faster consolidation times. Paste fill is batched on surface and transported through boreholes and piping to the stopes.

- **CAP (Composite Aggregate Paste)** – combination of above mentioned
Backfill Types

*We as well divide backfill by tailings types (gold tailings, copper tailings, lead-zinc tailings, coal tailings etc.)
Objectives of backfill

- To ensure the mining operation geotechnically
- Increasing extraction ratio (maximize recovery)
- Extension of mine’s life and increase overall mine NPV
- Decreasing foot print and surface disposal - environmental impact
- Optimizing water consumption
- Ensure mining operation for mine closure and surface collapse.
Backfill operation concepts

- There are different geomechanical requirements (and conditions) in underground mines related to backfilling.
- Backfill material (tailings, sand, water, binder) are unique for each mine operation.
- There are different types of backfill designs as well as surface conditions considerations.
- There are different types of transportation systems in mine backfill.
- For these reasons backfill is a complex system requiring good understanding of all total interactions.
- Admixture choice is a result of all interactions and overall cost savings which provides the highest benefit to the mine.

Ref: EDUMine-Professional development, 2003

Very important consideration for choice of admixture are conditions in backfill plant and UG!!!
Holistic approach in backfill mix design

Requirements:
- Flow retention
- Time (mining against the fill)
- Safety

Conditions:
- Temperature SF
- Temp UG
- Distances V/H

Source: BELEM Tikou, BENZAAZOUA Mostafa Predictive Models For Prefeasibility Cemented Paste Backfill Mix Design, 2006 Nancy
Backfill system complexity

Complex interaction within the matrix:

- Tailings influences water chemistry
- Tailings influences flowability, water content, binder needs and its performances (strength dev.)
- Water influences binder hydration and its kinetics
- Conditions influence rheology, binder hydration and safety
- Admixtures influence rheology, hydration and strength enhancement
- Tailings, binder and water influences admixtures performances

Major Question always remains the same:
For what price! € ???
Backfill optimization

1. Backfill management and ownership (who does what?)

2. Understanding the requirements – fill strength and exposure (at what time), flowability requirements - Flow will occur when the driving head exceeds the wall shear stress (capacity, safety and distance)

3. Understanding the material properties and characteristics

4. Understanding the conditions and limitation (every solution has limitation mechanical or chemical)

5. Understanding the correlations and interactions of material characteristics and properties, mechanical set up (rheology and in-situ behavior) vs requirements and cost

6. “If I change something here consequently something will change in the backfill flow too” – Backfill mass flow chart (Mineral processing-rheology- UCS-Side wall dilution-mineral processing =COST)
Summary important for admixtures selections

- Different mining methods with:
  - Different requirements (final UCS and strength gain over time – early strength)
  - Mining cycle (mining against the fill)
- Different types of backfill with different properties
  - Different preparation of the materials
  - Mix designs and layouts of the plants
  - Transportation
- Different materials used
  - Different interaction (Aggregates properties (PSD, Mineralogy -Sulfide attack), Binders, water)
  - Behavior of materials as well remaining chemistry
  - Cost
- Conditions above and UG
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Backfill Admixtures

Backfill admixtures are chemicals or blends of chemicals that are added to fill during the mixing (or transportation) in order to improve the properties of the fill while it is still fresh and flowable (before hardening).

Most admixtures do not undergo a chemical reaction with cement or tailings. The mode of action is based on electrostatical or physical interaction with cement or tailings particles. Exceptions are some retarders and in particular some accelerators which chemically interact directly with the cement hydration process and it’s chemical equilibria.
Admixtures

- Quite often formulated with other admixtures types – blends.
- Admixture blends provides better effect in the mix design facilitating transportation, placing and hardening of the fill.
- Logistically is also less complex with single admixture as compared to several admixtures (storage, dosing units etc)
- Chemical composition of admixtures can vary depending on the market (cement type, conditions and requirements)
Type of admixtures

Admixtures types

Water reducers
  - LRWR
  - MRWR
  - HRWR or SP

Retarders & hydration control
  - Normal retarders
  - Hydration control

Accelerators
  - Set accelerators
  - Hardening accelerators

Viscosity modifiers

Foams

Special purpose admixtures
  - Anti-washout (underwater) admixtures
  - Pumping aid
  - Bleeding reduction
  - Other (customised)
Water reducing admixture

- Admixture which, without effecting the consistency, permit a reduction in the water content of a given fill mix or which without affecting the water content of a given fill mix increase the slump (decrease yield) – improve flowability. Or produce both effect simultaneously!
- Mostly used for binder optimisation, in some cases to decrease pressure and facilitate (or enable in certain cases) transportation and placing (self leveling paste)
- Terminology comes from concrete but in fact admixtures are dispersants and effect on the fill is water reduction and/or plasticising effect.

**Consistency adjustment can be achieved with water (cheap option), unfortunately it will influence negatively UCS as higher w/C ratio lower UCS is. More reliable option is with admixture.**
Why dispersing effect is important

1. Improve flowability
2. Provide condition for binder optimisation
3. Get better packing, hence lower permeability and finally better UCS also lower strength degradation over time (same to same comparison base)
4. More tailings (higher solids) – eco aspect
5. Better mixing and uniformity
6. Lower w/c ratio for same consistency (flow) – higher strength or faster mining cycle
7. Lower pressure lost per length of pipes
Pipeline Pressure drop when admixture used in paste backfill operation
MasterRoc MF 501

Control 320mm  With Admixture 550mm
MasterRoc MF 900

Control 320mm

With Admixture 660mm
Binder optimization – water reduction

![Yield stress and UCS charts](image-url)
Retarders and hydration control admixtures

“Admixture which extends the time to commencement of transition of the mix from the plastic to the rigid state”

The main purposes of delaying setting time are:

- To offset the accelerating effect of high ambient temperature (hot weather)
- To keep the fill workable throughout the entire transport, placing and finishing periods (CPF; CAF; CRF). Particularly important when transporting the fill over large distances, and for the elimination of cold joints. Cemented fill is a time dependent system!
- To improve safety factor
- Decrease maintenance time and binder lost (colloidal mixer)
Flow retention

![Flow retention graph](image)
Effect on UCS

![Graph showing the effect of different amounts of water on UCS (Ultimate Compressive Strength) over time.](image)

- **UCS [MPa]**: The graph displays the UCS values at various time points for different water concentrations. The UCS values range from 0.845 to 7.0 MPa.
- **Time [days]**: The x-axis represents the time in days, ranging from 0 to 180.
- **Water Concentration**: The graph compares the effect of 800 ml/t, 1000 ml/t, 1200 ml/t, and 1400 ml/t on UCS.

From the graph, it is evident that the UCS increases with time and water concentration, with the highest UCS observed at 1400 ml/t.
Hydration control measurements and influence on early strength development

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**ETA*, tan(delta)\(\eta^*\) Betrag(Viskosität)

DL/77.5%sc/4.25%bc/MMF701(450mL/t) (16.2.2012)
ST22-6V-16-SN44781; d=0 mm
- Betrag(Viskosität)

Measurable delay in hydration reaction

Early strength
VMAs

Admixtures which rheologically change the fill, improving stability, controlling segregation and enhancing pumpability (transportability) providing higher UCS (better distribution and packing of fines and binder particles within the matrix of the fill)

Most VMA’s are based on high molecular weight polymers with a high affinity to water. By the interaction of functional groups of the molecules with the water and surfaces of the fines, VMA's build up a three dimensional structure in the liquid phase to increase the yield stress of the fill, creating a stable engineered structure (fines + conveying liquid forming a vehicle – R. Cooke)
Effect in CAF

Without rheology modifier

With rheology modifier
The Rheology Difference

Aggregate particles have separated from mixture

Rolling edge vs. Flat edge

Aggregate particles are suspended within the mixture and are present all the way to the perimeter.
Segregation influence on mechanical properties in CHF

Different layers

Different mech. properties

- 0.1 MPa ???
- 10 -20 MPa !!!
- 0.1 MPa ???

Sand
Binder
Sand
What admixture can do?

- Economics (binder savings)
- Performances (higher and/or faster strength development; transportability improvements (segregation control, lower viscosity), placement (tide filling) and uniformity)
- Transportation & production efficiency (higher capacity, higher flow, lower pulsation, lower maintenance, facilitate cleaning, lower wearing etc)
- Workability retention and safety
- Environment (water savings, less binder - more tailings (eco efficiency), lower porosity etc)
For 4% binder at 80.5% solids
Mechanical and chemical
In some cases multiple benefits can be achieved:
- Binder optimization
- Faster curing = faster mining against the fill
- Better flow/production rates
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How to choose right admixture?

Although there exist only a limited number of basic admixtures classes (families) chemistry, there are most likely hundreds of admixtures available (blends, customized, special etc)

Procedure:
1. Material characterization (tailings and water)
2. Cement specification and characterisation
3. Definition of performance requirements and specifications (flow, UCS, retention etc)
4. Conditions (time needed for several operation (mixing, transporting, placing, hardening etc)), temperature
5. Tentative selection of admixture
6. Lab screening
7. **Approximate cost calculation** and potential benefits
8. Field testing
9. Final cost calculation based on 1:1 test and outcomes (complex analysis and **total value proposal**)
10. Contact experts – unique BASF dedicated backfill team
Lab testing organisation

Pre-screening

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<td>Drying and disaggregating</td>
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<tr>
<td>Homogenizing and sub-sampling</td>
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<tr>
<td>Material characterization</td>
</tr>
<tr>
<td>Tailings, sands and aggregates (or rocks)</td>
</tr>
<tr>
<td>Binder and Process water</td>
</tr>
<tr>
<td>Physical properties</td>
</tr>
<tr>
<td>Chemical properties</td>
</tr>
<tr>
<td>Rheological testing</td>
</tr>
<tr>
<td>MCR Rheometer</td>
</tr>
<tr>
<td>HAAKE VT</td>
</tr>
<tr>
<td>UCS</td>
</tr>
<tr>
<td>Early strength</td>
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<td>Reporting and technical proposal</td>
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Decision
Backfill lab set-up: Particle size distribution analysis

To Analyse the influence of PSD on the rheology behaviour of the tailing mixes.
Backfill lab set-up: Differential thermo analysis

To evaluate the chemical reactivity of binder materials, as well as the effect of types of water on the hydration behaviour of the binders.
Backfill lab set-up: Microscopy for mineralogy

To estimate the dependence of the shape of mineral particles from tailing materials observed by light microscope on rheology of tailing mixes.

The shape of Quartz and other mineral particles in Sunrise Dam Mine
Backfill lab set-up: Chemical analysis via ICP-OES

To study the chemical composition of tailing, binder materials as well as the water from mine sites on the action mode and efficiency of chemical admixtures applied.

Chemical analysis for Nickel Rim

<table>
<thead>
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<th>Heavy metals</th>
<th>Nickel Rim Mine, Canada</th>
<th>Nickel Rim Mine, Canada</th>
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<tbody>
<tr>
<td></td>
<td>Tailings</td>
<td>Binder</td>
</tr>
<tr>
<td>Antimony mg Sb/kg ds</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Arsenic mg As/kg ds</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Lead mg Pb/kg ds</td>
<td>130</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Cadmium mg Cd/kg ds</td>
<td>&lt;0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Chromium mg Cr/kg ds</td>
<td>161</td>
<td>28</td>
</tr>
<tr>
<td>Cobalt mg Co/kg ds</td>
<td>188</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Copper mg Cu/kg ds</td>
<td>1160</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Molybdenum mg Mo/kg ds</td>
<td>7</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Nickel mg Ni/kg ds</td>
<td>976</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Mercury mg Hg/kg ds</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Thallium mg Tl/kg ds</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Zinc mg Zn/kg ds</td>
<td>164</td>
<td>29</td>
</tr>
<tr>
<td>Tin mg Sn/kg ds</td>
<td>12</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rare earth and other elements</th>
<th>Nickel Rim Mine, Canada</th>
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<tr>
<td></td>
<td>Tailings</td>
<td>Binder</td>
</tr>
<tr>
<td>Aluminum % as Al2O3</td>
<td>11</td>
<td>8.5</td>
</tr>
<tr>
<td>Barium mg Ba/kg ds</td>
<td>862</td>
<td>835</td>
</tr>
<tr>
<td>Cesium mg Cs/kg ds</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Cerium mg Ce/kg ds</td>
<td>103</td>
<td>95</td>
</tr>
<tr>
<td>Gallium mg Ga/kg ds</td>
<td>21 &lt;10</td>
<td></td>
</tr>
<tr>
<td>Germanium mg Ge/kg ds</td>
<td>&lt;50 &lt;50</td>
<td></td>
</tr>
<tr>
<td>Lanthanum mg La/kg ds</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Neodymium mg Nd/kg ds</td>
<td>34</td>
<td>38</td>
</tr>
<tr>
<td>Niobium mg Nb/kg ds</td>
<td>&lt;10 &lt;10</td>
<td></td>
</tr>
<tr>
<td>Rubidium mg Rb/kg ds</td>
<td>60 &lt;50</td>
<td></td>
</tr>
<tr>
<td>ds := dry solids</td>
<td></td>
<td></td>
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</tbody>
</table>

BASF
We create chemistry
Backfill lab set-up: Rheology measurement (MCR 301)

Rheological tests, both in rotational and oscillatory mode, allow the integration of a wide range of temperature accessories and special modules.

Kidd Creek Mine: Effect of MMF 701 (red curve) on the yield stress compared to the reference (blue)
Flow retention at controlled temperature
Backfill lab set-up:
Rheology measurement

Flow Cylinder Systems (1 L and 5 L) to investigate the effect of solid content, type and dosage of admixtures on the flow time of mix in pipe.
Early strength development for MMF 701

Transition from paste to plastic state

ETA*, tan(delta)
Backfill lab set-up:
Strength development with 4-needle penetrometer FORTUDO

Through monitoring the strength development by continuous recording, the accelerating of the admixtures on the setting and hardening process is demonstrated.

Effect of MasterRoc MF product on the hardening process
UCS determination

UCS @ 83 % sc + 4.5 % bc

Dosage of MMF 701 (mL/t)

<table>
<thead>
<tr>
<th>Dosage (mL/t)</th>
<th>2 day</th>
<th>7 day</th>
<th>14 day</th>
<th>28 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.38</td>
<td>1.59</td>
<td>1.59</td>
<td>1.59</td>
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<tr>
<td>200</td>
<td>3.16</td>
<td>3.25</td>
<td>3.25</td>
<td>3.25</td>
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<tr>
<td>400</td>
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<td>3.26</td>
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<td>3.26</td>
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<td>600</td>
<td>3.48</td>
<td>3.58</td>
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<td>800</td>
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<tr>
<td>1000</td>
<td>3.96</td>
<td>4.08</td>
<td>4.08</td>
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</tr>
<tr>
<td>1200</td>
<td>3.97</td>
<td>3.95</td>
<td>3.95</td>
<td>3.95</td>
</tr>
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Chemical design

1. Multidisciplinary knowledge (Technical & engineerical, material science, chemical engineering, economy)
2. Comprehensive understanding - Correlations of different factors on performances and cost of BF
3. Dedicated Resources (facilities and People)
4. Continuity, Consistency and Quality in the backfill work (lab and industry testing)
5. Measurable performances vs requirements for cost-effective solution (complex cost model or Total Value Proposition)
6. Sustainability and eco-efficiency
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Cost of the backfill in the industry is mostly measured through binder (cement) cost as represent biggest portion

Other cost is representing:

- Energy
- Labor
- Maintenance
- Administrative
Consider:

- Direct (and measurable)
  - cost on binder savings
  - Water savings
  - Improved production rates
  - Lower maintenance and brake down time

Associated cost savings and benefits:

- In mining operation faster gain of UCS (quicker re-entry)
- Better performances of the fill (lower dilution factors)
- Lowers surface disposal (higher solids of tailings UG)
- Recovery on water and potential savings in reagents or pH regulators (back to mineral processing)
- Lower labor cost and energy cost for improved efficiency
- Better amortization of the equipment
- Ecology – lower carbon footprint, lower water consumption, higher utilization of tailings in filling
Sustainable approach – Total mining cycle

**Economy**
- Total cost savings (cement) 0.30 - 0.45 €/t
- No capital cost for more capacity

**Ecology**
- Binder savings at least 12.5% in lab scale potentially more in full scale
- Water savings 7-8%

**Sustainability**
- Lower water consumption (more recycled water with needed pH)
- Less tailings on tailings pond

**Productivity**
- Production increase for 10% (from similar project in 1:1 scale test from 300 t/h up to 330 t/h)
- Lower labor/operational cost due to higher production
- Longer run will be permitted without stop for cleaning – higher productivity
Backfill in mining cycle