Advanced Refractory Materials and their role in Furnace Integrity/Furnace Containment

Workshop 1
Tap hole refractory materials – taphole clay

APPLICATION AND TESTING OF TAPHOLE CLAY

Workshop Structure and Learning Context

07:30-08:30 Registration and early morning refreshments
08:30 Workshop Start
(*08:30-10:30 Andrie*)
10:30-11:00 Mid-morning break
(*11:00 – 12:30 Izak*)
12:30-13:30 Lunch
(*13:30-14:00 Izak*); (*14:00-15:00 Neha*)
15:00-15:15 Afternoon refreshments
(*15:15-16:30 Neha*)
16:30 Workshop ends

Workshop Structure and Learning Context

1. <u>Presentation 1 (60 min):</u> **Taphole refractories**
   - ➢ Function, Features, Ideal Behaviour
   - ➢ Classification – Raw Materials, Binders
   - ➢ Testing – Product Development, Quality Control, Site-testing
2. <u>Presentation 2 (60 min):</u> **Tap hole Operations & Management**
   - ➢ Taphole Processes & Clay Features
   - ➢ Safety & Risk Management – Scenarios
   - ➢ Extra: AI as a systems monitoring tool

Fundamental Concepts of Taphole Refractories

Types of Taphole Refractories

1. Bottom/Hearth

Function: Designed to contain molten metal (and sometimes matte), resist chemical attack from metal and slag, withstand high static loads and severe thermal gradients, and enable long furnace campaign life.

Insulating Lining | Safety Lining | **Working Lining**

➢ **Working Lining**

- Carbonaceous: Anthracite/Graphite/Semi-Graphite blocks, ramming paste + graphite blocks, ramming paste
- Oxide: Alumina (Al_2O_3), Magnesia (MgO-)*

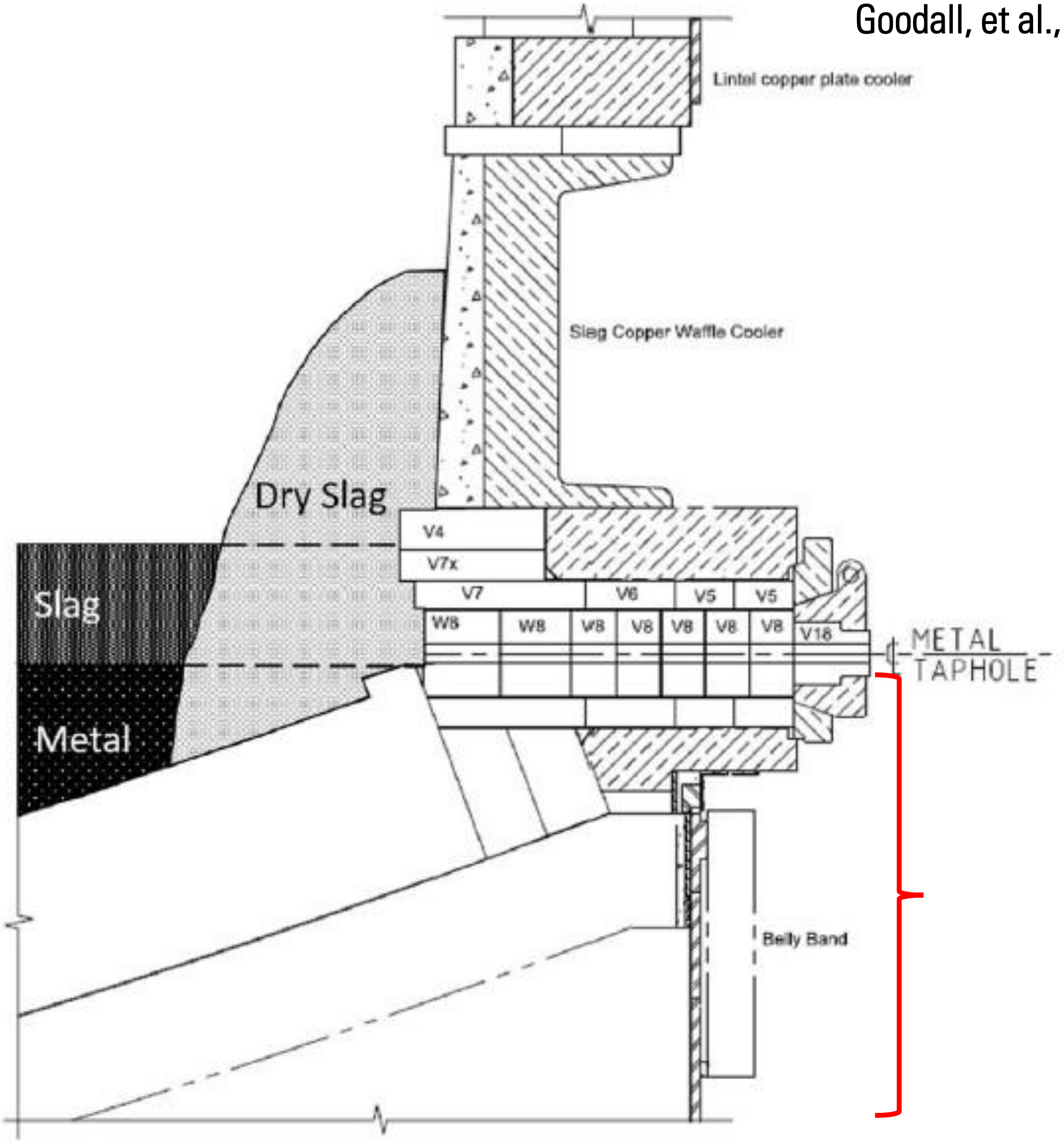
Insulating Lining | **Safety Lining** | Working Lining

➢ **Safety Lining**

- Brick / Castable
- Oxide: Alumina (Al_2O_3), Magnesia (MgO-)
  - Al_2O_3-SiO_2, >Al_2O_3, >MgO, Al_2O_3-MgO (spinel)

**highly oxidising environment / freeze lining approaches*

Goodall, et al.,



Types of Taphole Refractories

Goodall, et al.,

2. Tap hole & Tapping Channel

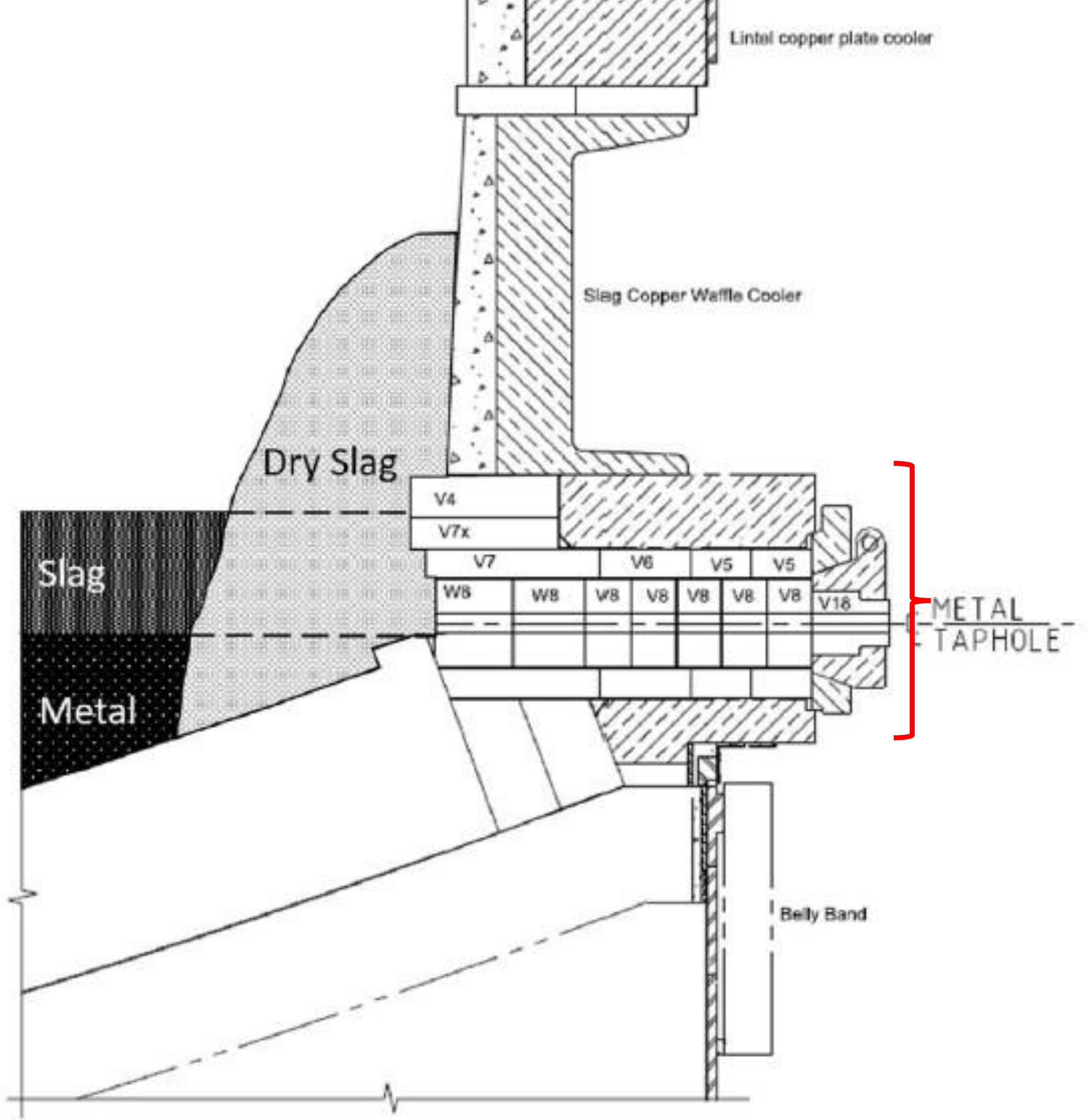
Function: Designed to maintain structural integrity during repeated tapping, resist thermal shock, oxidation, and metal/slag attack*, and ensure reliable bonding with the taphole clay.

- Brick / Blocks
- Oxide: **70–90% Al_2O_3**, Andalusite | Al_2O_3-Cr_2O_3 (Pt) (Spinel)
- <Carbon: Al_2O_3-SiC-C (SAF & BF) / Al_2O_3-SiC (EAF)

Tapping Channel (inside)

Function: The taphole clay must reliably seal the furnace between taps, open cleanly during drilling, briefly withstand metal temperatures, maintain constant molten flow rates, and rebond effectively after each tap.

- *Consumable refractory*
- Oxide: **Al_2O_3-SiC-C**, SiO_2-C (maintain)
- Carbonaceous: Anthracite, Synthetic carbon (repair)



Types of Taphole Refractories

3. Sidewalls

Function: Designed to resist slag line corrosion while accommodating thermal gradients and expansion without loss of mechanical integrity.

- *Governed by slag basicity*

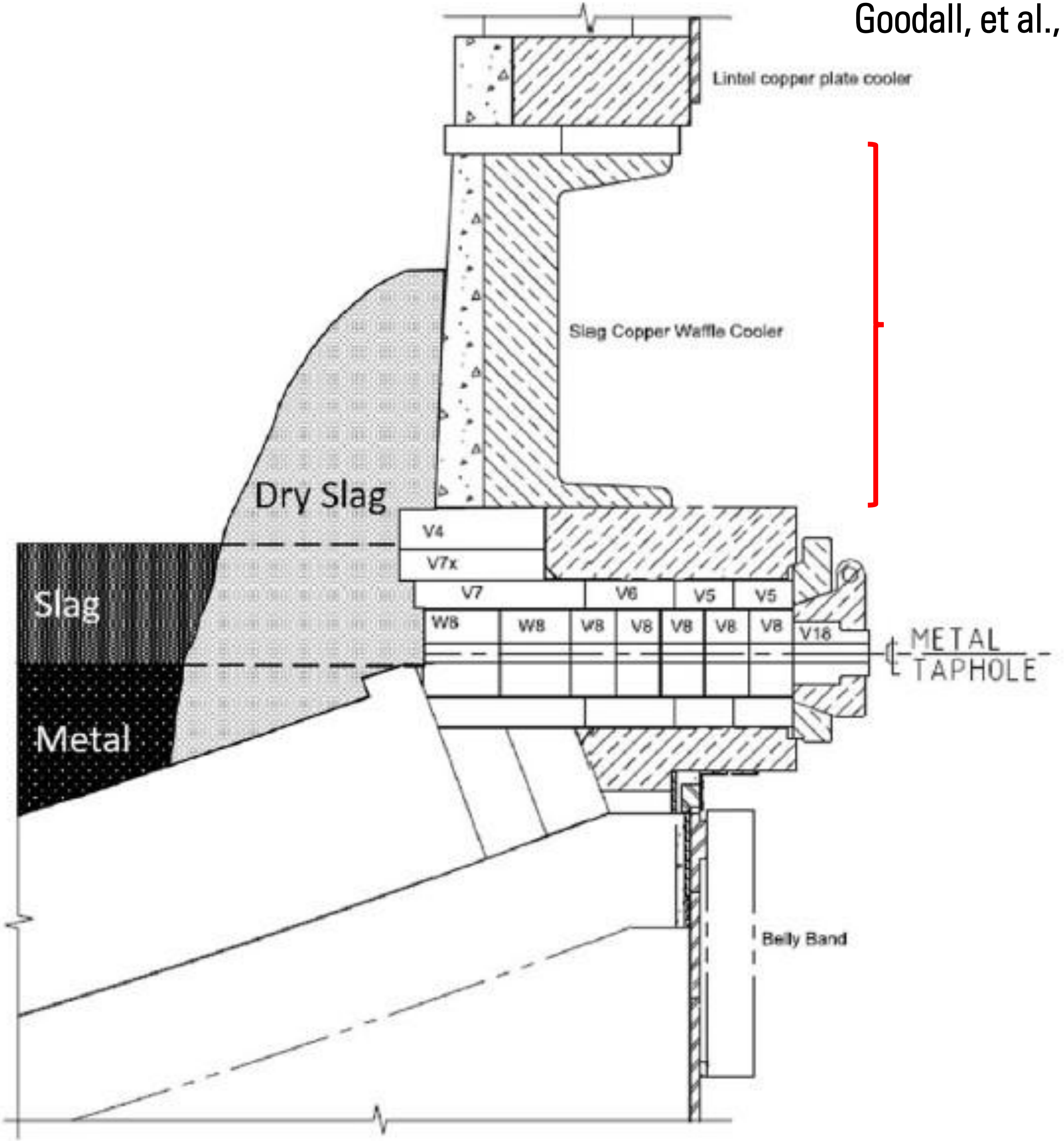
Basic Slag (Steel/Ferro-chrome)

- Oxide: **MgO-based Bricks** (MgO, MgO-Spinel, MgO-C*)

Neutral/Acidic Slag (Ferro-alloy/Non-ferrous)

- Oxide: Al_2O_3, Al_2O_3-SiC-C, Al_2O_3-SiO_2 (Andalusite)

Goodall, et al.,



Taphole Clay/Paste – What is it?

Definition, Function and Features of Taphole Clay

Technical Definition

"A plastic, unshaped refractory material used to plug and seal the tap hole of a blast furnace or similar pyrometallurgical furnace between tapping operations"

Refractory Function

Function Category	Description
Primary	**Plug** and **Seal** Tapping Channel between Taps
Secondary	Controlled drilling & reliable opening Protection of Tapping Chanel Controlled Emptying of Furnace Safety & Extend Furnace Life

Definition, Function and Features of Taphole Clay

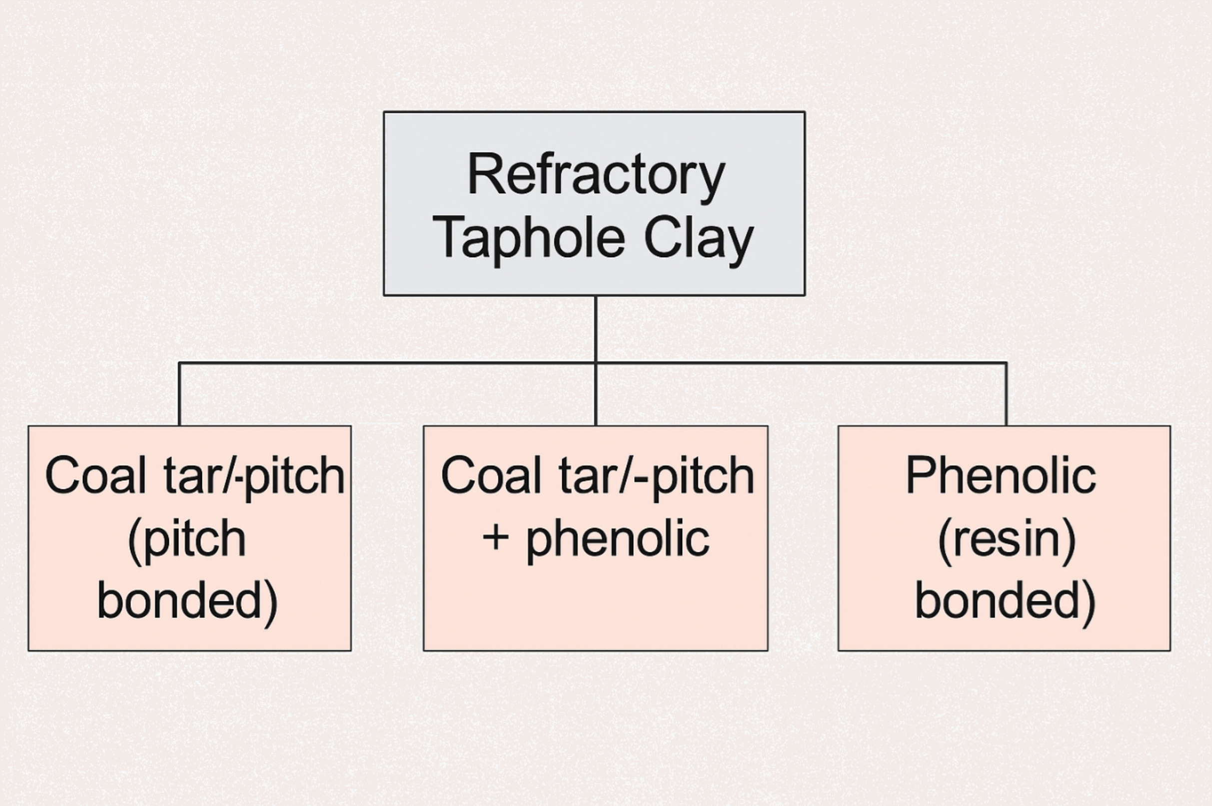
Refractory Features

- Plastic & workable
  - *Reliable plugging*
- Good adhesion
  - *Reliable plugging & integrity*
- Rapid strength development at low temperature (<600°C)
  - *Short holding time*
- Good high temperature strength & dimensional stability
  - *Seal integrity (load & pressure)*
- Controlled drilling-ability
  - *Short drilling time & safety*
- High wear resistance
  - *Integrity of tapping channel*
- Adequate erosion during tapping
  - *Consistent tapping performance*
- Thermal cycling stability
  - *Maintain rapid heating cycles*

Functional Classification of Taphole Clay – *Chemical/Technical*

Chemical Classification

Conventional unshaped refractories classified on oxide system; taphole clay classified on binder system.



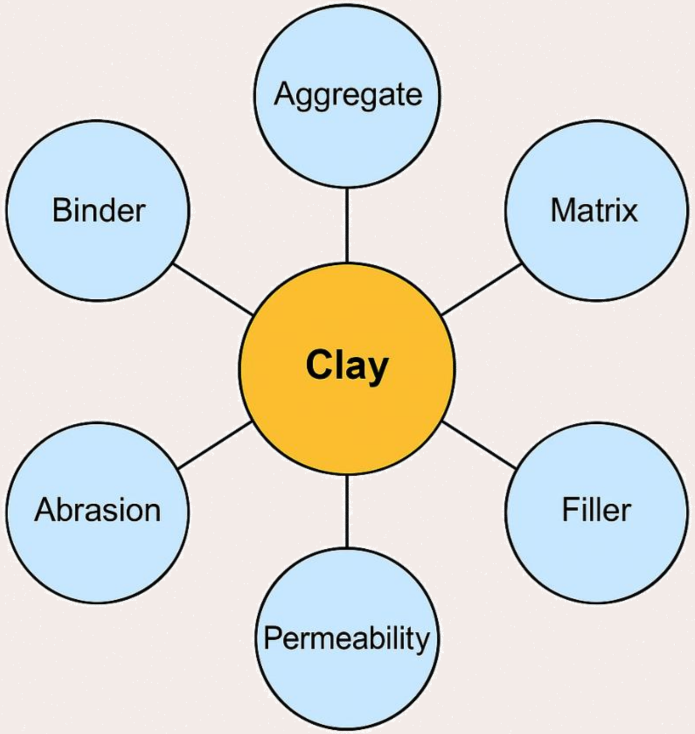
Functional Classification of Taphole Clay

Technical Classification

Tapping channel refractories can either be classified as clay (maintain) or pastes (repair).

Chemical Composition

Governed by maximum operating temperature and slag corrosion (composition).



Functional Classification of Taphole Clay

Chemical Composition of Taphole Clay

Governed by maximum operating temperature and slag chemistry.

Commodity	Conditions	Taphole clay composition	Clay raw material type
Iron (blast furnace)	Moderate operating temp (1300-1400°C) High operating temp (1500-1600°C) High operating temp + long casting duration (high wear) High operating temp + severe thermal/chemical wear	35-45% Al_2O_3 40-50% Al_2O_3 45-60% Al_2O_3 >60% Al_2O_3 + SiC/Si_3N_4/carbon	Calcined clay/high silica raw material Calcined clay + enrichment of Al_2O_3 Andalusite/Mulcoa Bauxite/tabular alumina/combinations
Ferroalloy/non-ferrous	More severe local wear	>55% Al_2O_3 + SiC	Bauxite/tabular
Temporary plugging mass*			

Functional Classification of Taphole Clay

Chemical Composition – Taphole Clay

Functional Components	Raw Materials	Function
Aggregate	Calcined Clay (Al_2O_3-SiO_2(+)) Andalusite/Mulcoa (Al_2O_3-SiO_2) Bauxite/Fused/Tabular (Al_2O_3(+)) Quartz (SiO_2(+))	Structure, strength, wear, refractoriness
Matrix & Filler	Calcined Clay (Al_2O_3-SiO_2(+)) Andalusite/Mulcoa (Al_2O_3-SiO_2) Bauxite/Fused/Tabular (Al_2O_3(+)) Clay (Al_2O_3-SiO_2(+)-K_2O(+)) Microsilica (SiO_2(+))	Structure, strength, wear, refractoriness Adhesion & plasticity Extruding rheology
Permeable Component	Coal fines	Permeability for binder volatilization
Abrasive Component	Silicon Carbide (SiC) - *fines*	Erosion resistance
Sinter Components	Boron Carbide (B_4C) Silicon Nitride (Si_3N_4) Clay (Al_2O_3-SiO_2(+)-K_2O(+))	Enhance sintering at high temperatures
Binder	Carbonaceous/non-carbonaceous (no PAH) Resin Diluent (Ester-based oils, carbonaceous oils, i.e., anthracite, creosote)	Main binder (C-network former) Low-temp. strength Adjust binder viscosity - *workability*

Functional Classification of Taphole Clay

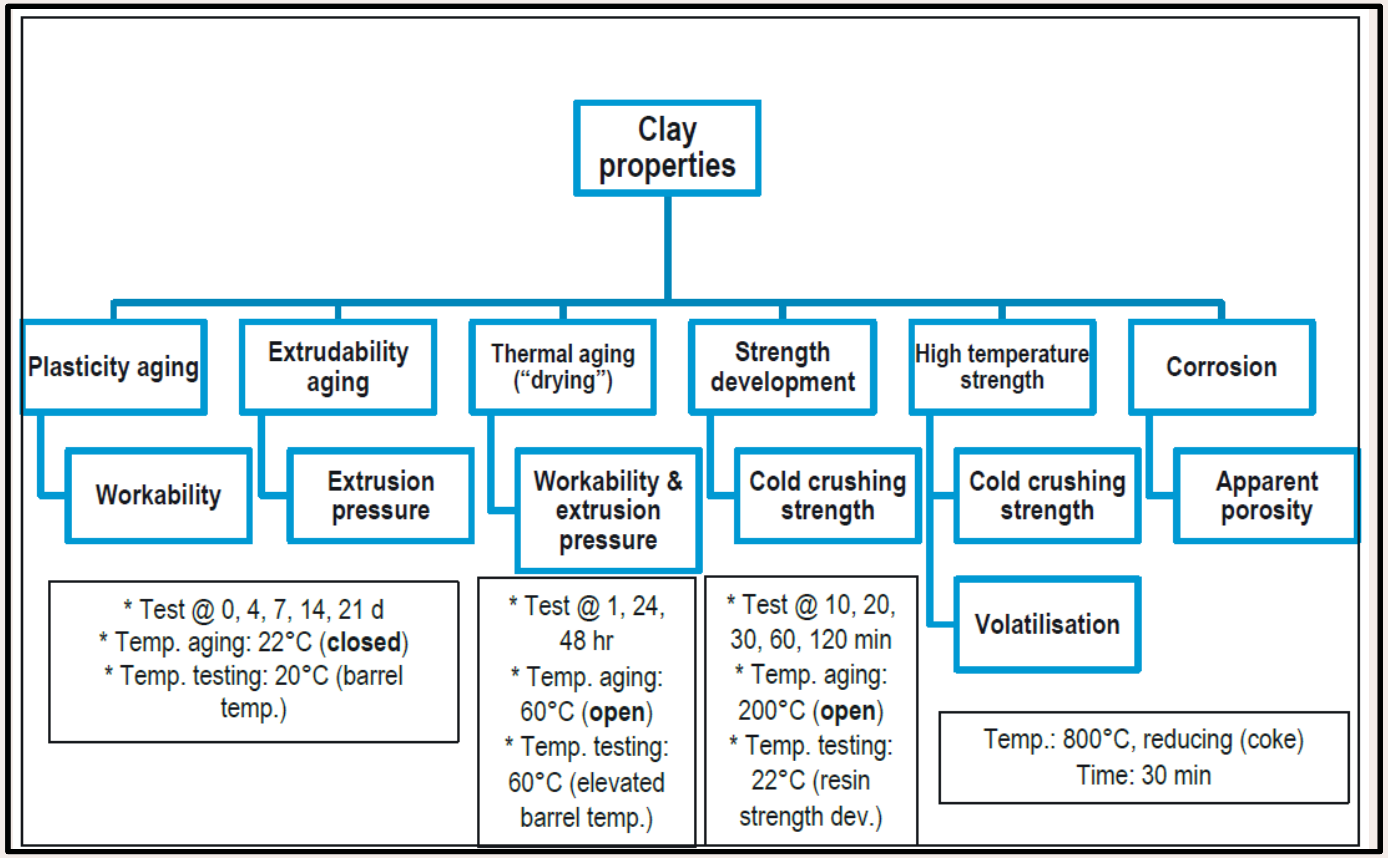
Chemical Composition – Taphole Paste

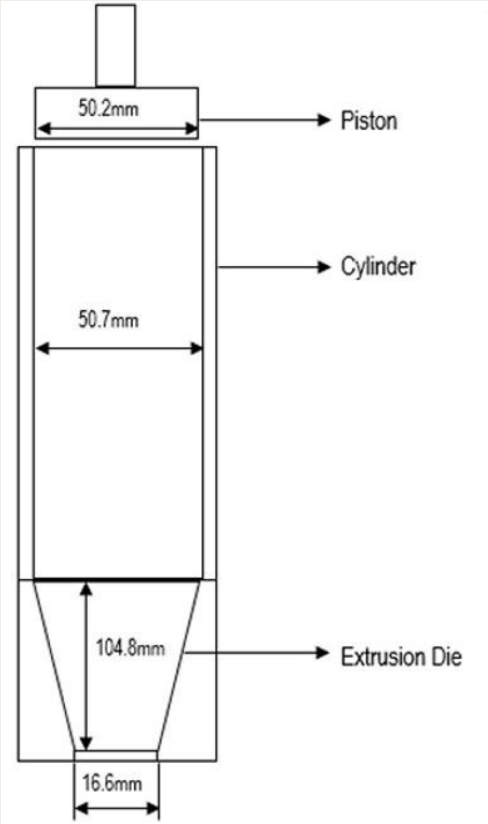
Functional Components	Raw Materials	Function
Aggregate	Anthracite (C) Petroleum Coke (C) Synthetic Carbon (C)	Structure, strength, wear, refractoriness
Matrix & Filler	Anthracite (C) Petroleum Coke (C) Synthetic Carbon (C) Clay (Al_2O_3-SiO_2(+)-K_2O(+)) Microsilica (SiO_2(+))	Structure, strength, wear, refractoriness Adhesion & plasticity Extruding rheology
Permeable Component	Coal/anthracite/petroleum coke fines	Permeability for binder volatilization
Abrasive Component	Silicon Carbide (SiC) - *fines*	Erosion resistance
Sinter Components	Boron (B) Si/Al fines Silicon Nitride (Si_3N_4) Clay (Al_2O_3-SiO_2(+)-K_2O(+))	Enhance sintering at high temperatures
Binder	Carbonaceous/non-carbonaceous (no PAH) Resin Diluent (Ester-based oils, carbonaceous oils, i.e., anthracite, creosote)	Main binder (C-network former) Low-temp. strength Adjust binder viscosity - *workability*

Testing of Taphole Clay – Product Development

Development Testing of Taphole Clay

Standardized & Non-standardized Testing





Extrusion Pressure (MEP)

Workability

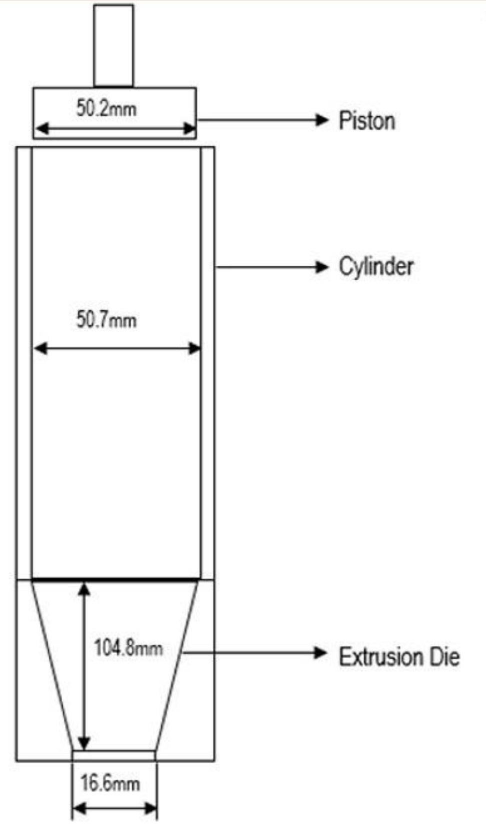
Izak Jian-Pierre Cameron, Investigating premature ageing of blast furnace taphole clay containing a resole resin and liquid pitch binder (MEng diss., University of Pretoria, 2021), http://hdl.handle.net/2263/78314.

Development Testing of Taphole Clay

Standardized & Non-standardized Testing – Workability (WI)

Standardized – ASTM C181 *(Standard Test Method for Workability Index of Fireclay and High-Alumina Plastic Refractories)*

- Workability Index described - measures how easily a plastic refractory can be extruded under controlled conditions
- Empirical: $WI \propto \frac{Amount\ Extruded\ (kg)}{Load\ Applied\ (N)} = \frac{W}{F}$
- W↑ at same pressure → more clay extruded
- F↑ for same output → harder to ram



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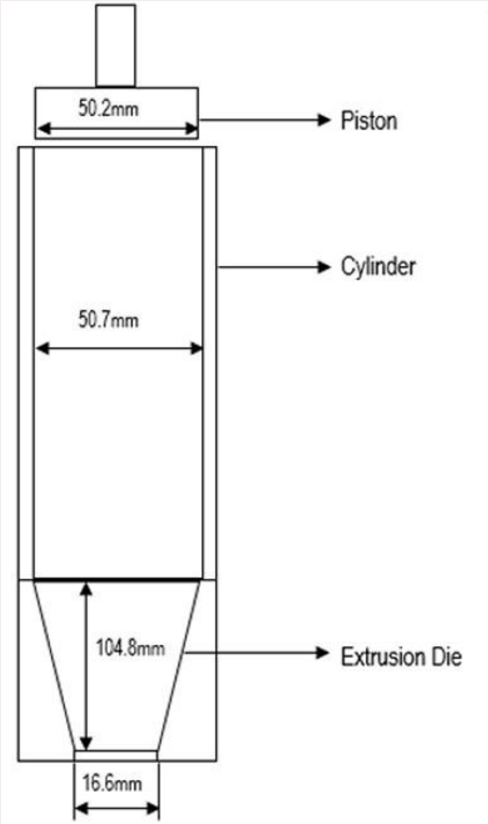
Development Testing of Taphole Clay

Standardized & Non-standardized Testing – Workability (WI)

Non-Standardized (WI reinterpreted)

- J. Steenkamp: The workability index of three tap-hole clays
- I. J-P. Cameron: Investigating premature ageing of blast furnace taphole clay containing a resole resin and liquid pitch binder
- Use of AFS sand rammer → fixed clay amount → constraint compression → change in height
- $WI\ (\%) = \frac{H_0 - H_n}{H_0}\ x\ 100$

H_0 = initial sample height; H_n = height after defined number of rams (3)



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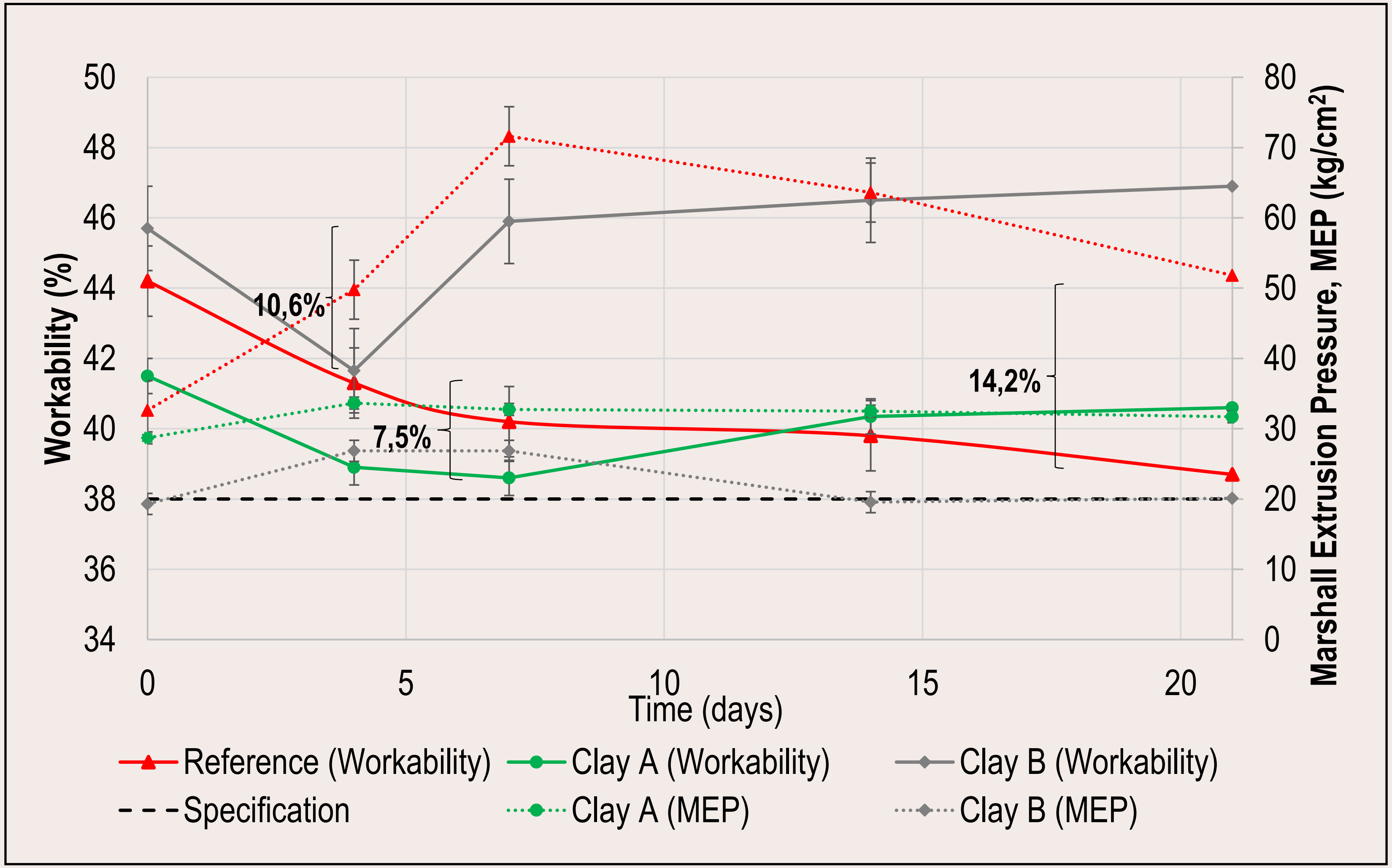
Development Testing of Taphole Clay (graphs)



Izak Jian-Pierre Cameron, Fundamental study of taphole clay behaviour with respect to the binder system and evaluation of alternative non-toxic binders (PhD thesis, University of Pretoria, 2024), http://hdl.handle.net/2263/96828.

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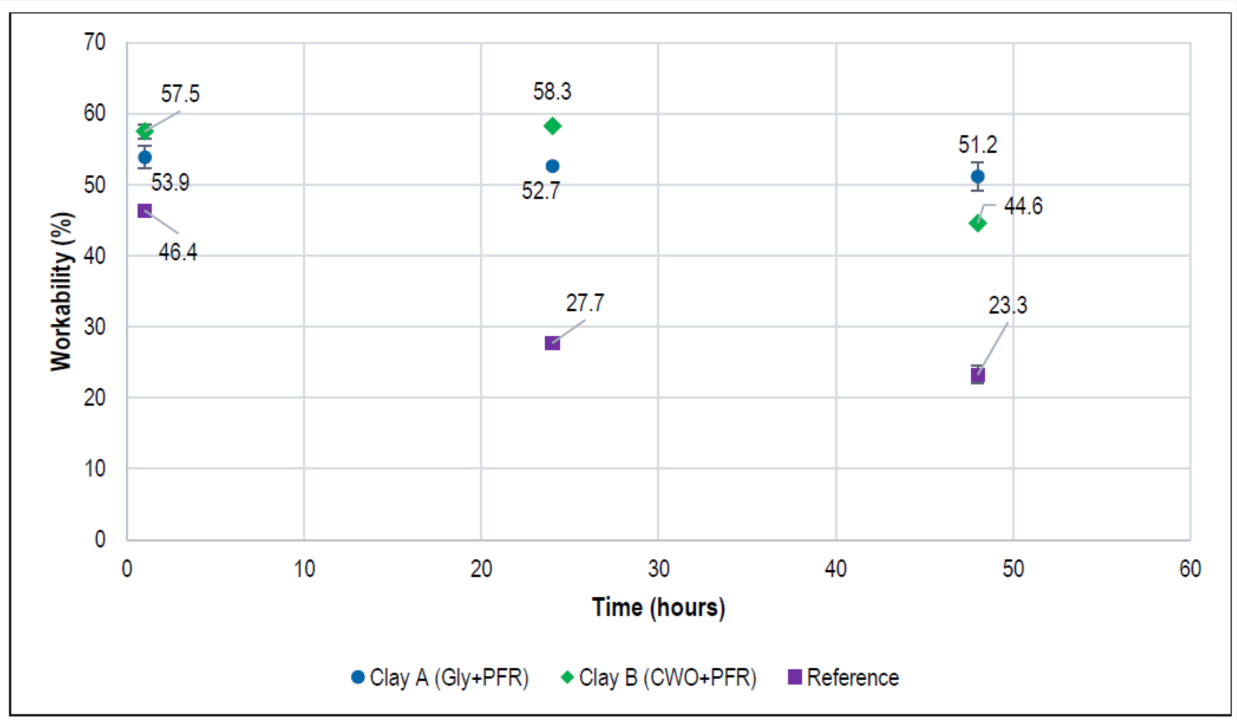
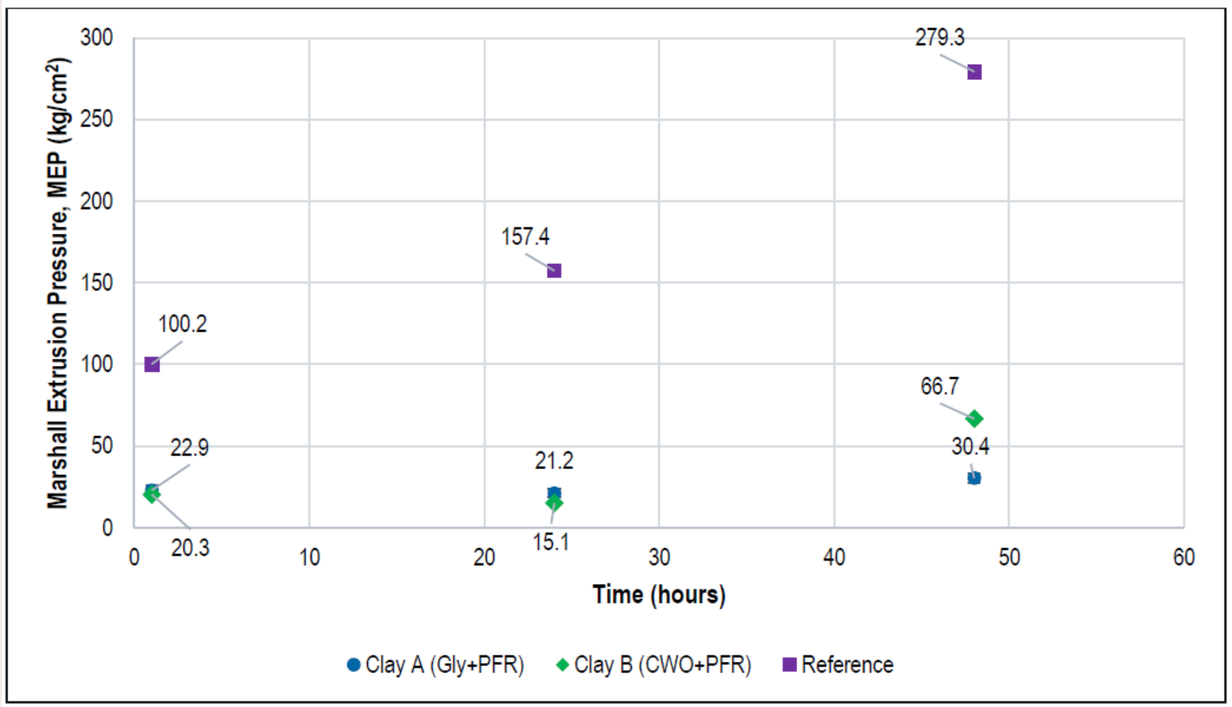
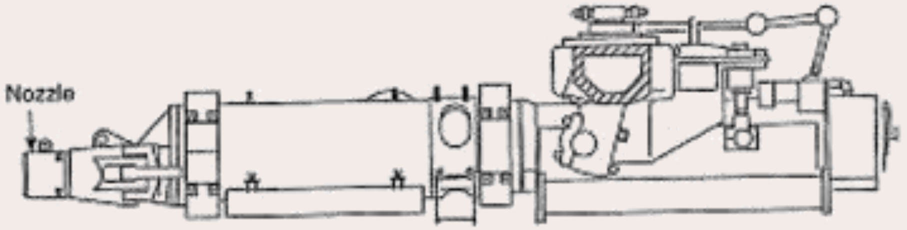




Hardenability/Drying-ability



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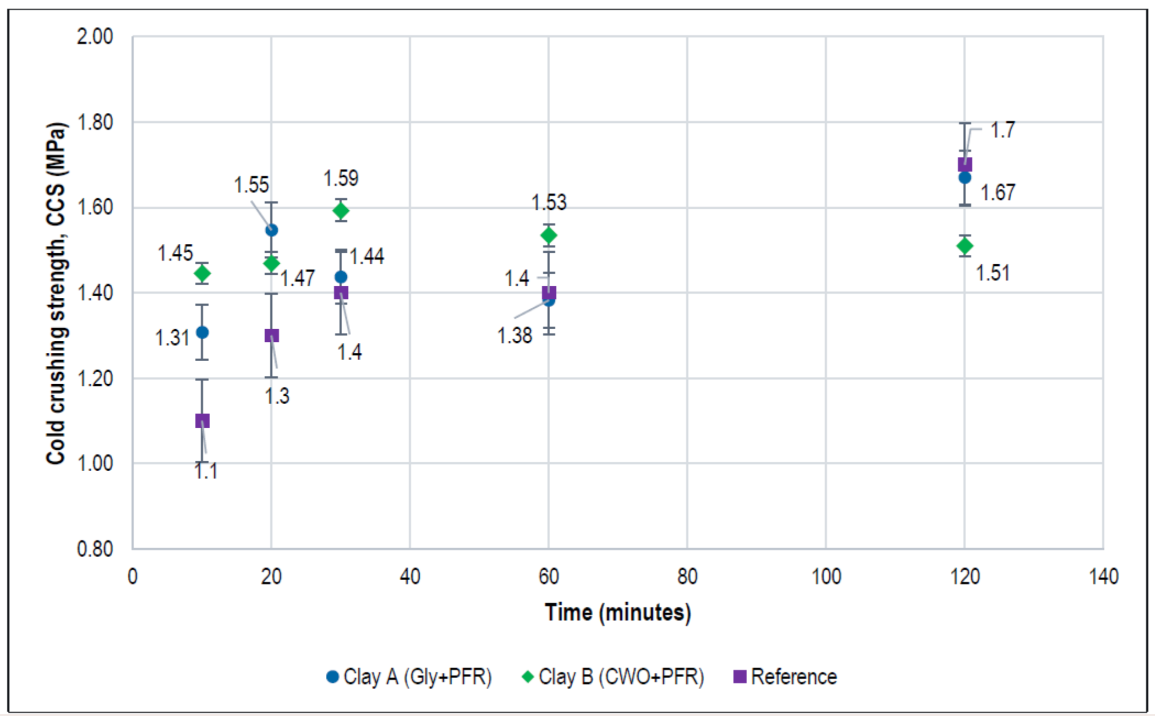
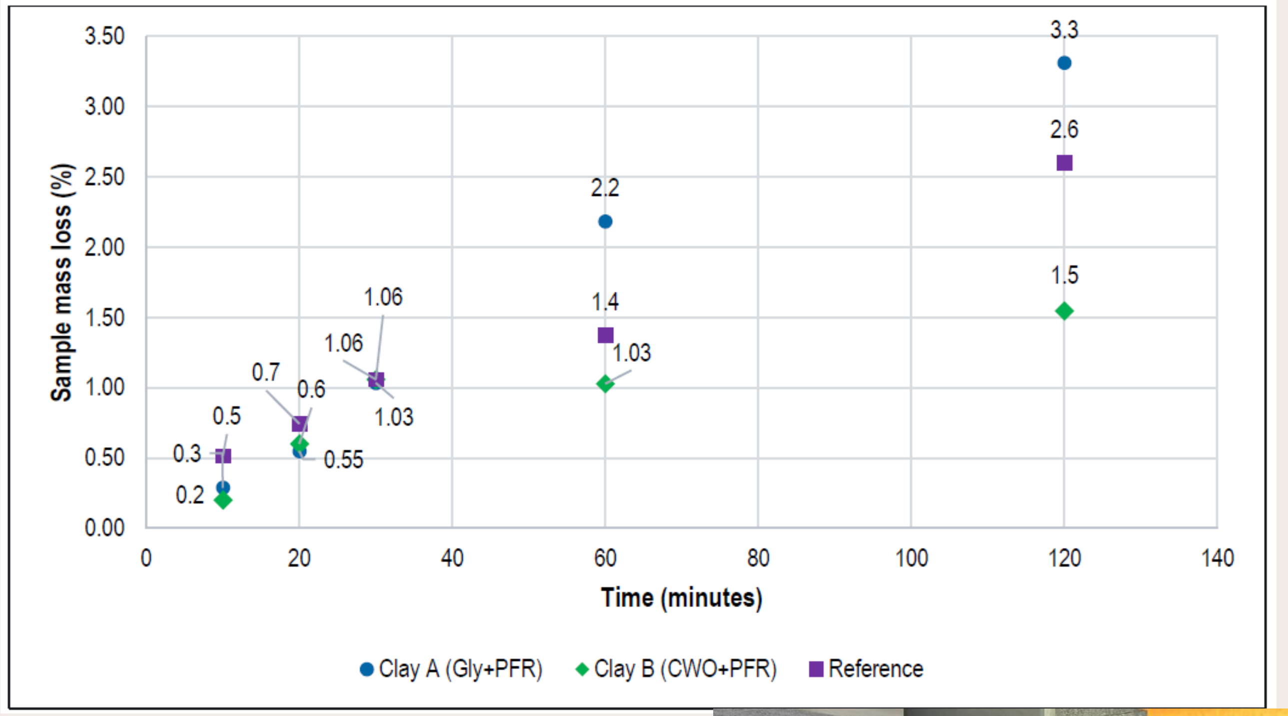
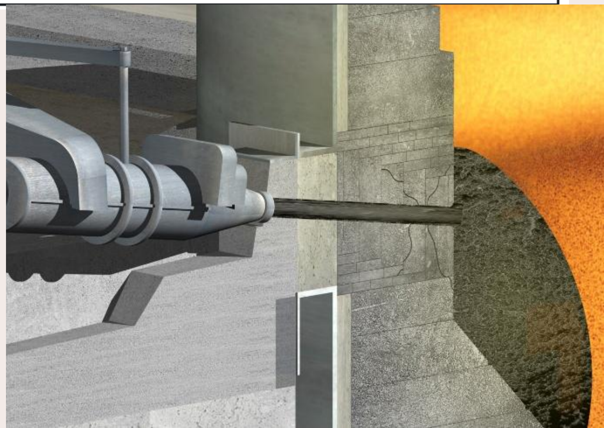




Strength Development



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Development Testing of Taphole Clay (graphs)

Property	Reference (CTht)	Clay A (Gly+PFR)	Clay B (CWO+PFR)
Volatile organic compound (VOC) (%)	21.3	14.6	13.8
Carbon yield (%)	12.4	10.3	11.2
Cold crushing strength (CCS) (MPa) (> 2.1 MPa)	3.1	2.4	-
Apparent porosity (AP) (%)	12.3	12.0	-

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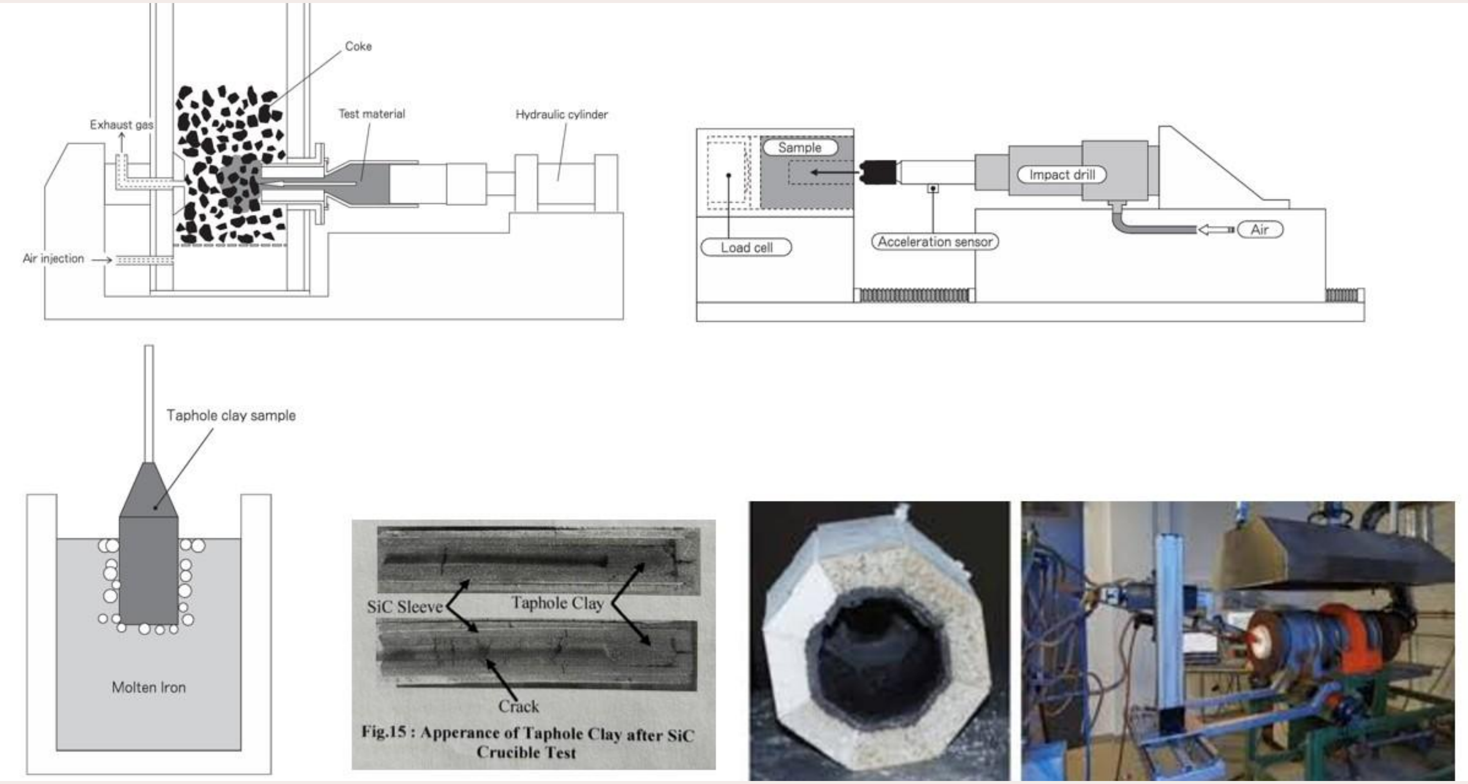
Development Testing of Taphole Clay

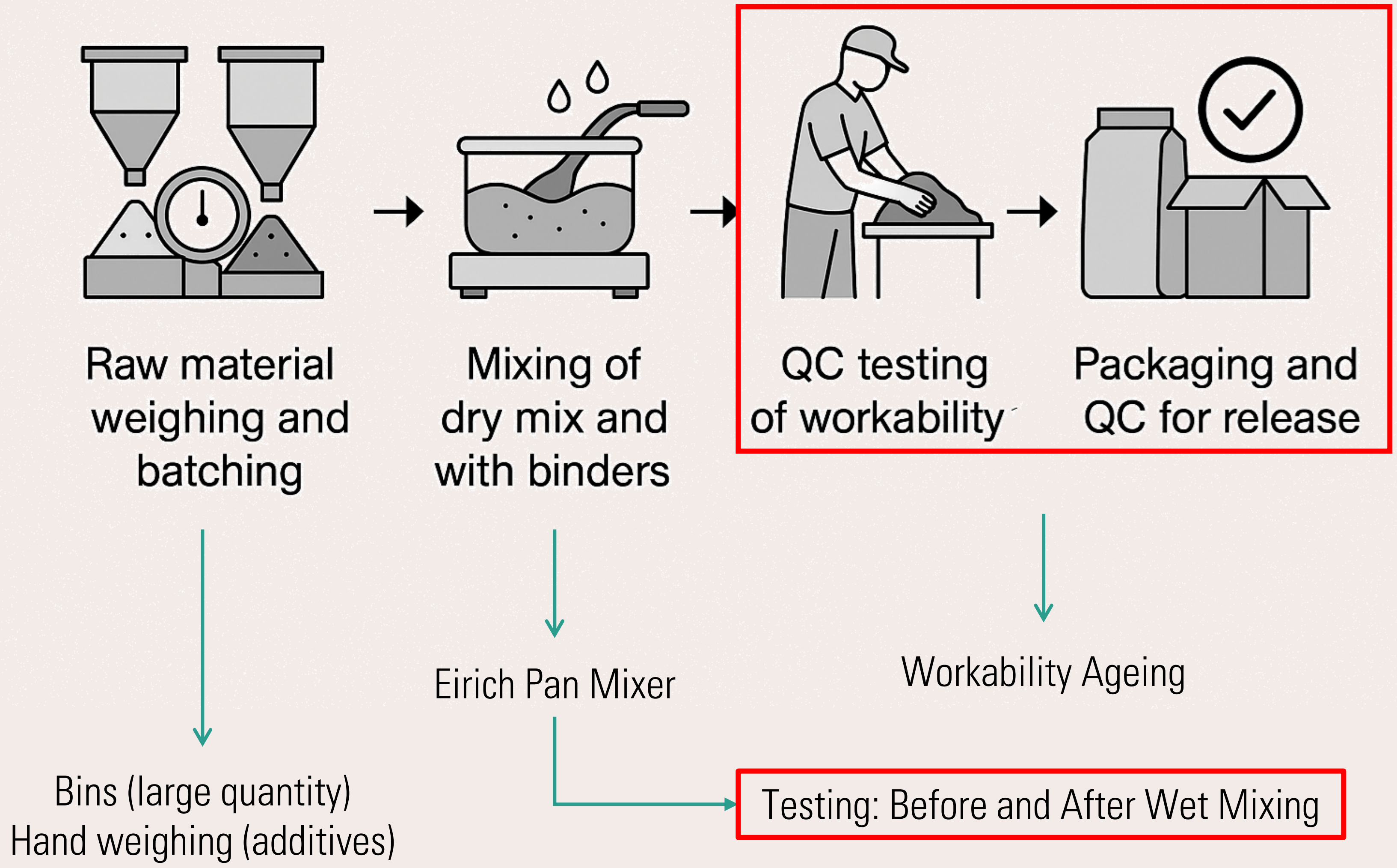
Specialized Clay Testing

- Mud Gun Simulations – Holding Time
- Drilling Simulations – Opening Time
- Hot Stage Microscopy/Hot Dip Testing/Rotary Slag Testing - Slag Wetting/Corrosion Tests
- In-situ compressive strength - High Temperature Strength Development
- Parallel Plate Viscosity – Rheology, i.e., workability
- Clay SiC sheath testing – Repair properties
- Post-mortem Analysis
- High Temperature Sintering/Mushroom Formation

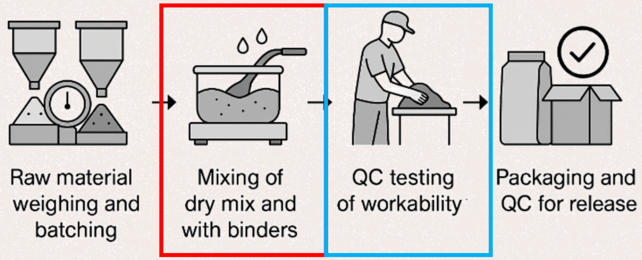


Testing of Taphole Clay – Quality Assurance

Manufacturing of Taphole Clay



Quality Assurance Testing of Taphole Clay

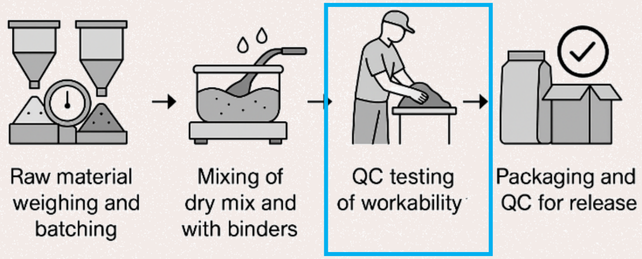


Dry Refractory Powder:
- Particle Size Distribution – Screening
- Bulk Density
- Chemical Analysis with X-Ray Fluorescence (XRF)
- Carbon Content
- Nitride Content

Clay Binder
- Flowability test with viscometer

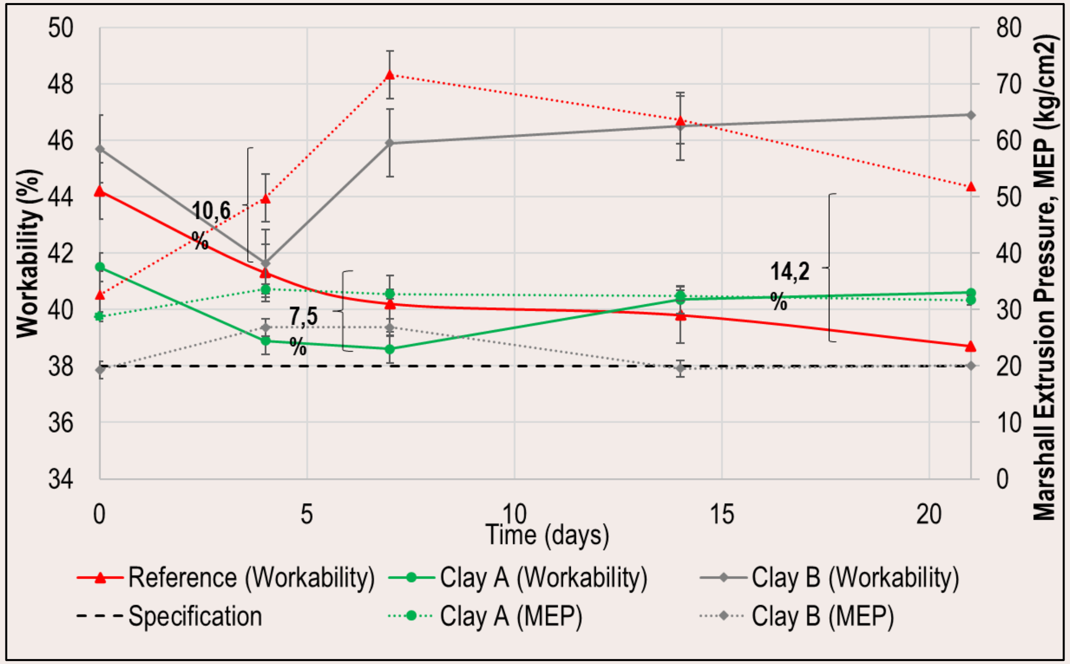
Taphole Clay
- Workability: Days 0, 4, 7,14, 21 – product release after stable workability drop
- Extrusion Pressure: Days 0, 4, 7, 14, 21
- Drying loss / volatile loss (Loss on Ignition)
- Cracking after drying (typically 110–200 °C) + Cold Compressive Strength
- Cold Compressive Strength – fired in reducing condition up to 1000°C OR in-situ CCS
- Volume stability / shrinkage after heating

Quality Assurance Testing of Taphole Clay



Taphole Clay

- Workability: Days 0, 4, 7,14, 21 – product release after stable workability drop
- Extrusion Pressure: Days 0, 4, 7, 14, 21



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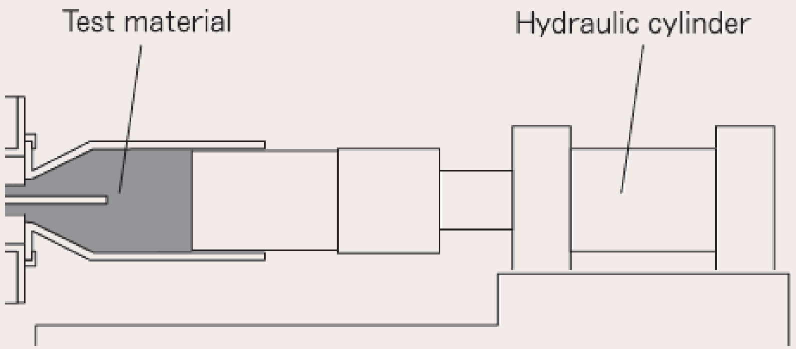
Site Testing of Taphole Clay

Taphole Clay

- Workability: AFS Sand Rammer
- Extrusion – "Elephant trunk" Test: Hydraulic Extruder



Taphole Operations & Management

Properties Governing Taphole Clay Performance

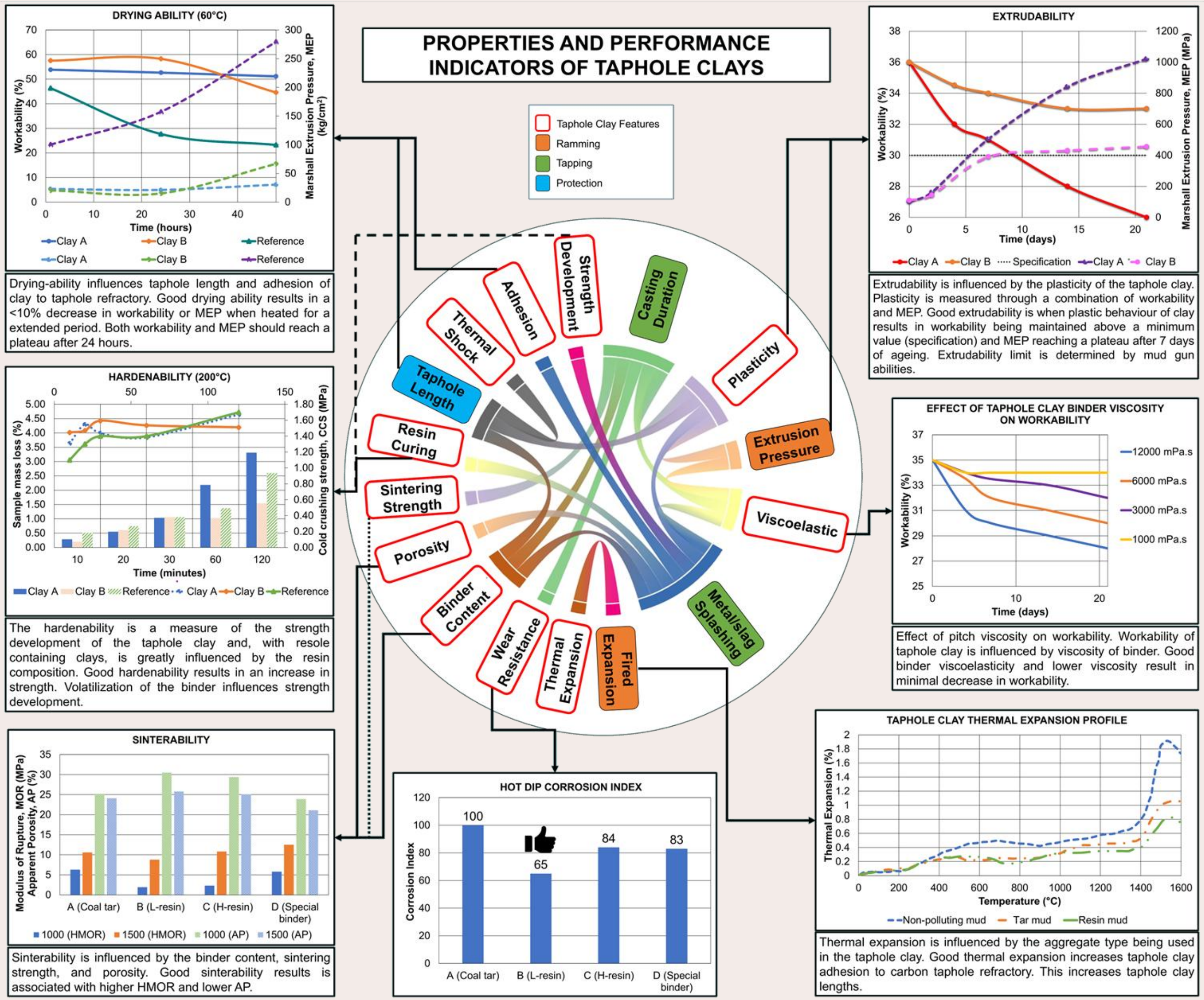
Taphole Processes & Clay Features

Tap hole Processes

- **Ramming:** Action of closing tap hole with clay to form a semi-permanent seal.
- **Tapping:** Action of forming a stable opening in the tap hole for molten material to drain from the vessel.
- **Protection:** Maintain integrity and performance of tap hole refractories to extend service life.

Taphole Clay Features

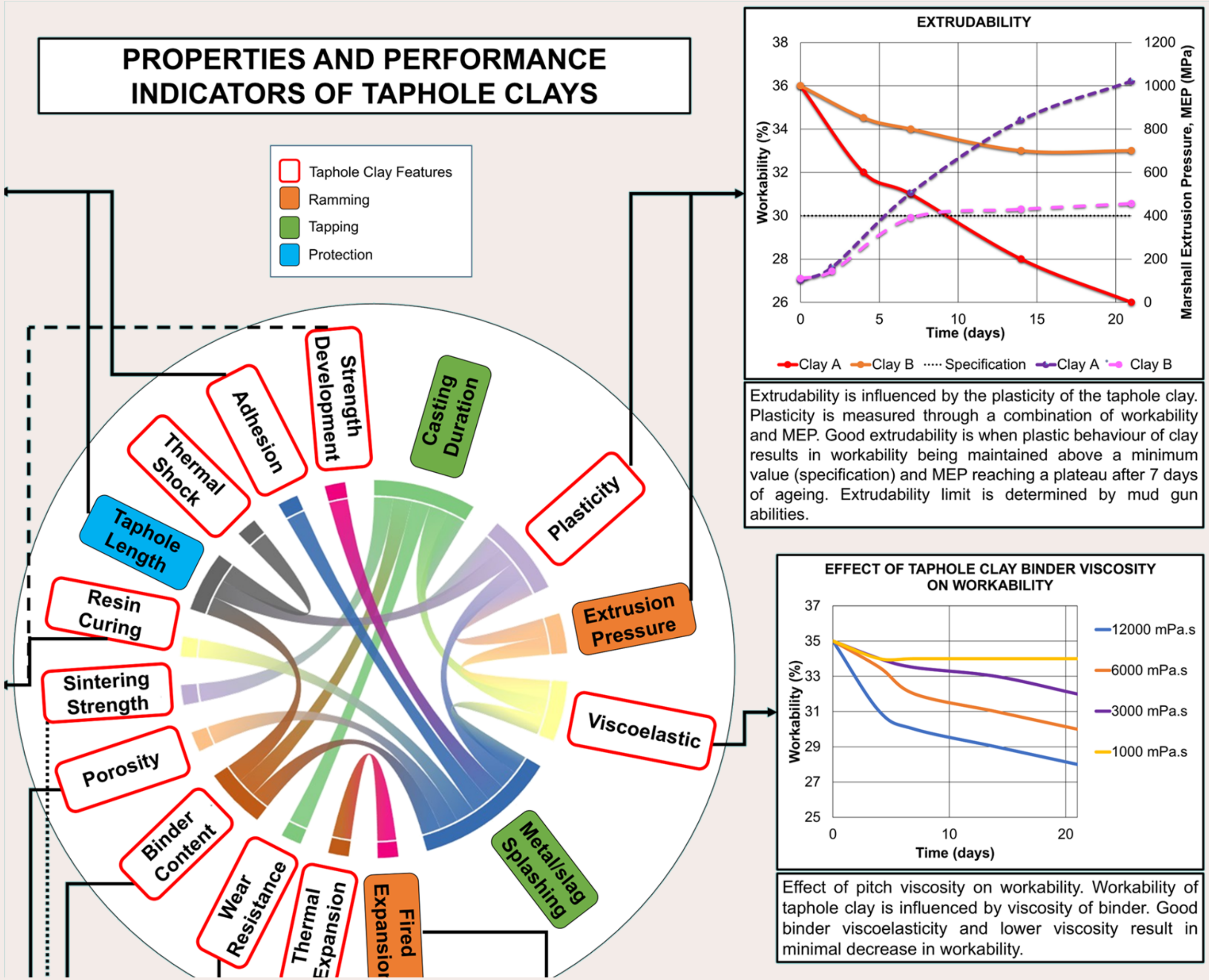
- Clay Plasticity
- Clay Rheology: Viscoelasticity
- Thermal Expansion
- Wear Resistance
- Clay Binder Content & Composition
- Clay Porosity
- Clay Sintering Strength
- Binder Curing Speed & Strength
- Thermal Cycling
- Clay Adhesion
- Clay Strength Development



I.J. Cameron and A.M. Garbers-Craig, ‘Understanding how the Binder System Influences the Properties and Process Performance Indicators of Taphole Clays’, refractories WORLDFORUM 16, no. 2 (2024), 28–33.

Taphole Processes & Clay Features

Clay Feature → What does it mean → What taphole process(es) does it influence



<u>Clay Plasticity (rheology)</u>

- *Measure: Workability ageing (23°C)*
- Governed by binder rheology (viscoelastic & low viscosity)
- Clay Rheology influences:
  - Mud gun extrusion (pressure)
  - Casing duration (heat-to-heat)
  - Molten splashing

<u>Extrudability (also rheology)</u>

- *Measure: Workability & Extrusion Pressure ageing (23°C)*
- Governed by clay plasticity → Plasticity governed by binder & clay rheology
- Clay Extrudability influences:
  - Mud gun extrusion (pressure)
  - Casing duration
  - Molten splashing
  - Taphole length

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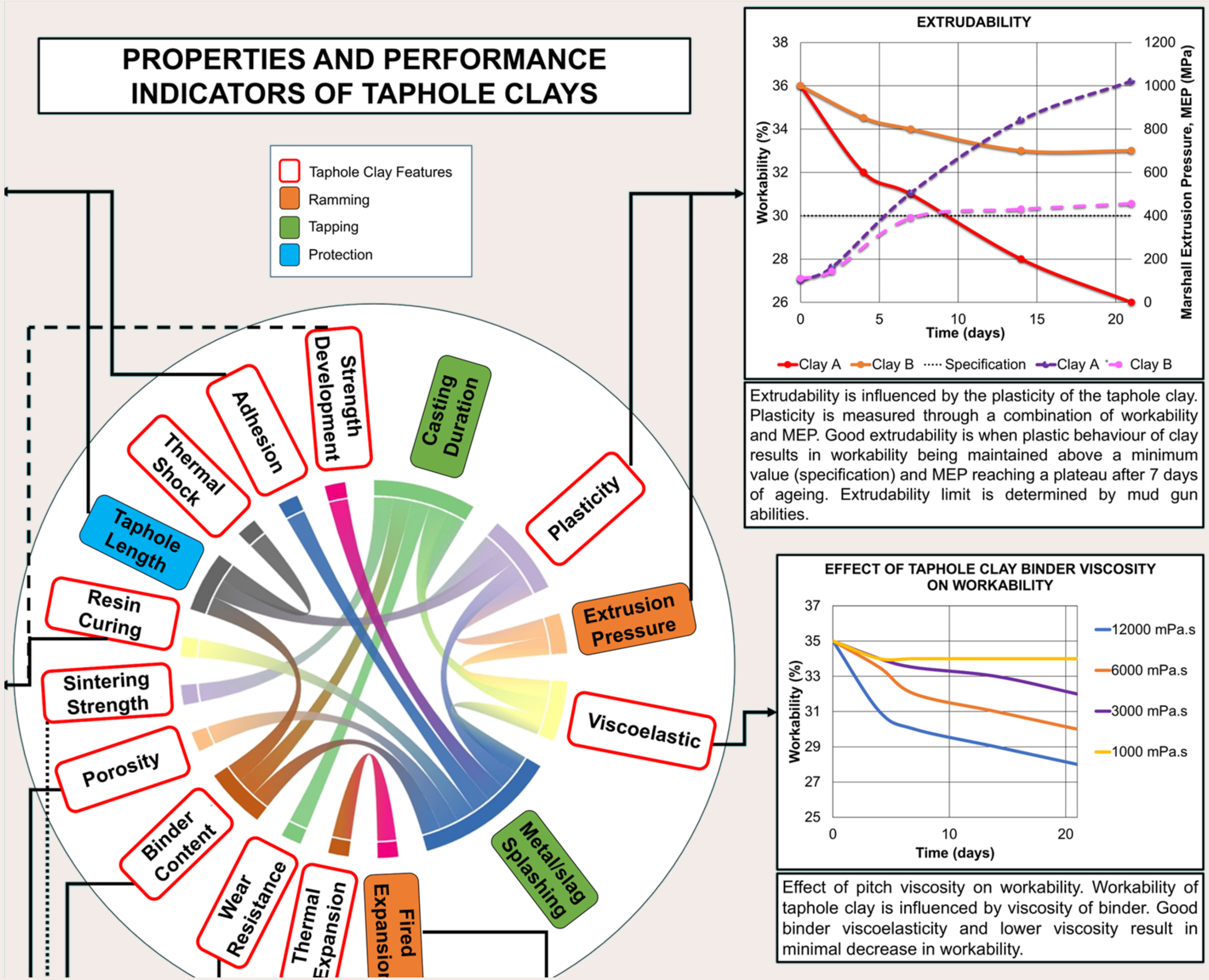
Taphole Processes & Clay Features

Clay Feature → What does it mean → What taphole process(es) does it influence

<u>Extrudability (aged clay reuse)</u>

- Extrudability governed by plasticity → Plasticity governed by binder (variable) & clay particle size distribution (fixed)
- Binder viscosity change → clay workability change
  - Subtle heating of clay (<40°C) – short period
  - Adjusting clay viscosity → blend of "fresh" clay with aged clay
  - Adjusting clay viscosity → glycerine? (supplier advise)



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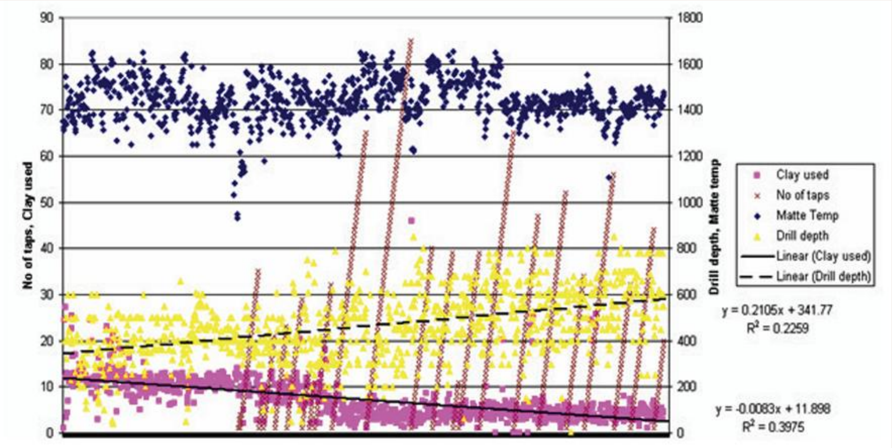
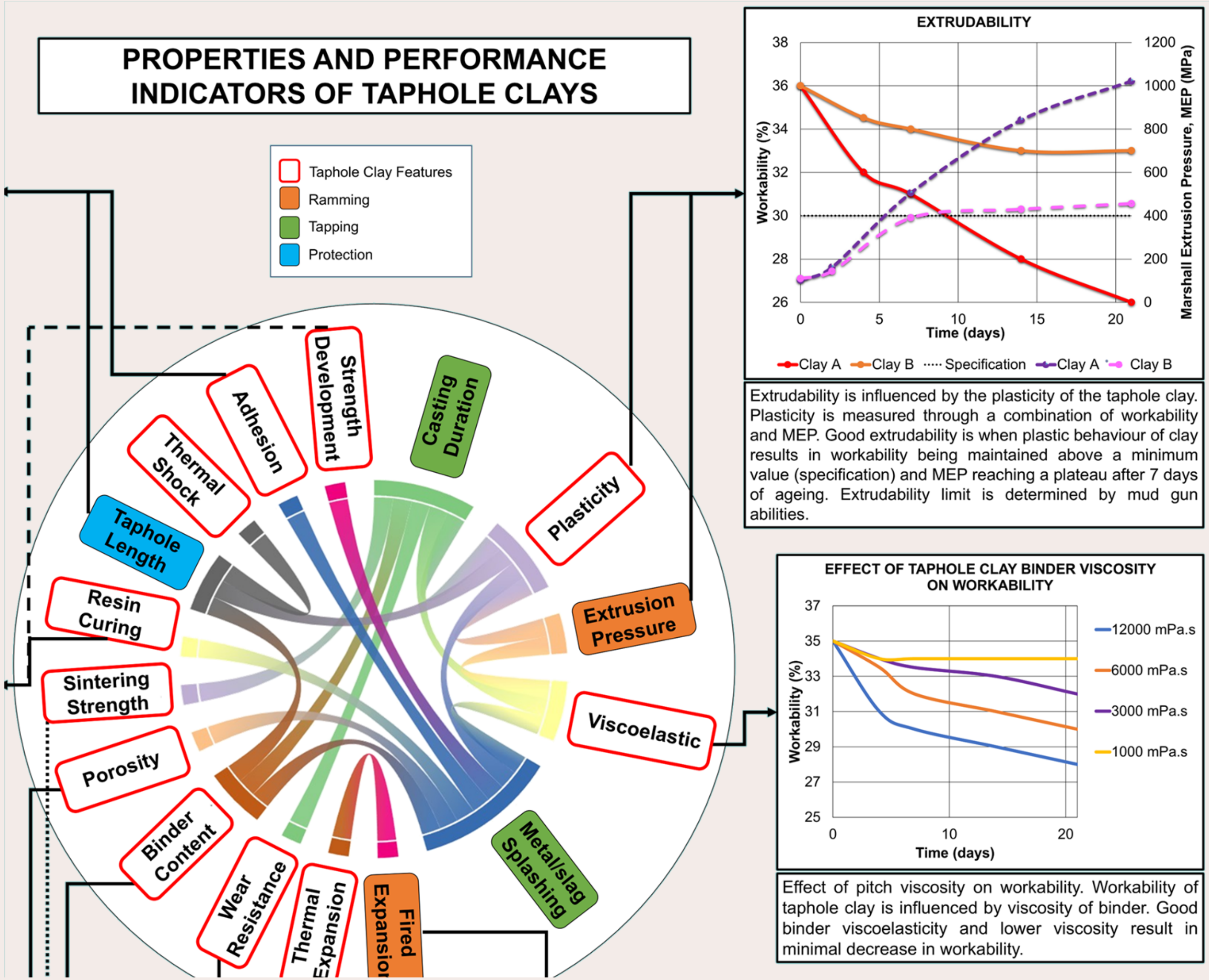
Taphole Processes & Clay Features

Clay Feature → What does it mean → What taphole process(es) does it influence

Extrudability (high vs. low)

- Clay Extrudability influences:
  - Mud gun extrusion (pressure)
  - Casing duration
  - Molten splashing
  - Taphole length





Nelson, L.R. and Hundermark, R.J., 'The tap-hole' – key to furnace performance, in Furnace Tapping Conference 2014, Southern African Institute of Mining and Metallurgy, 2014.

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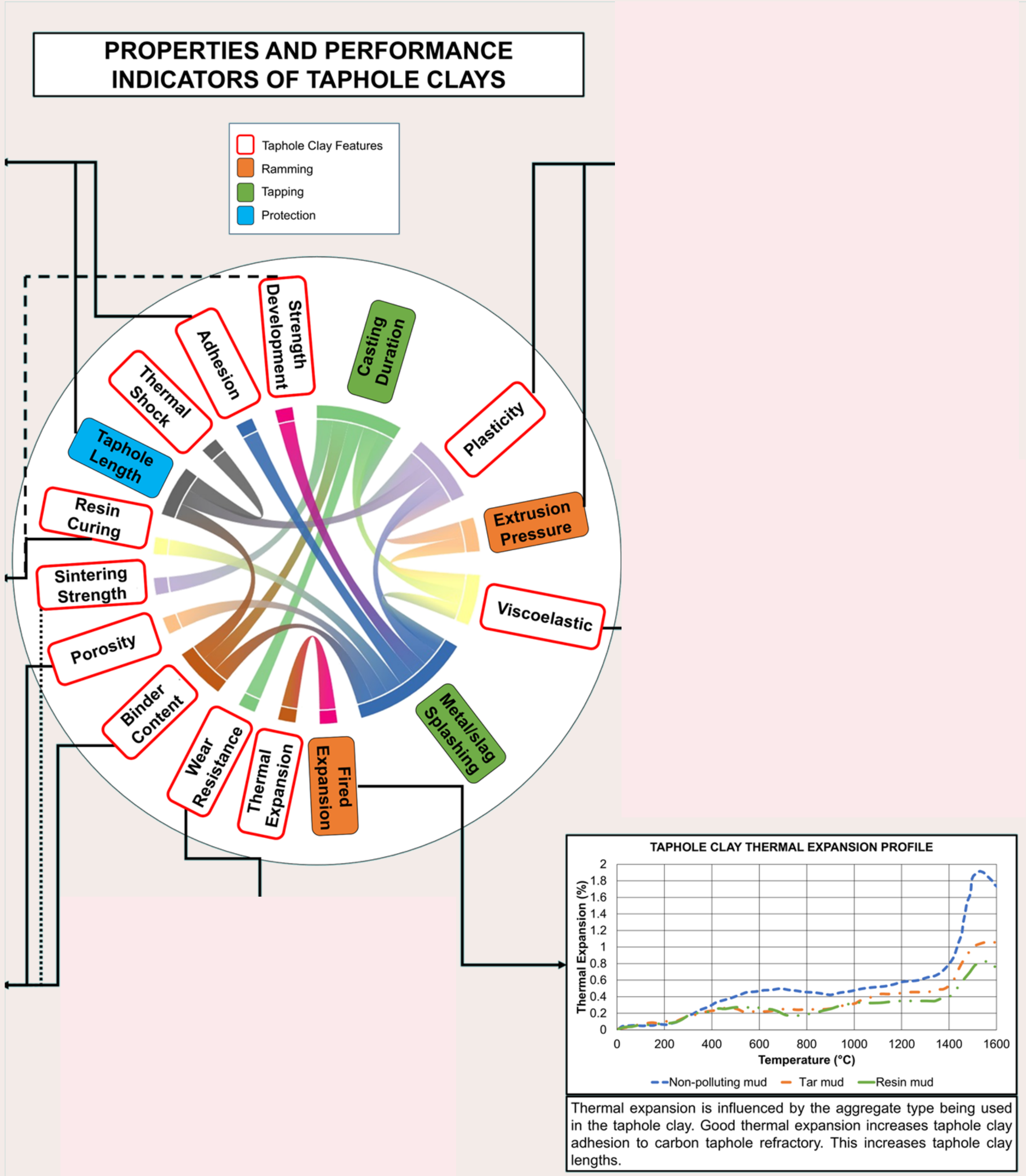
Taphole Processes & Clay Features

Clay Feature → What does it mean → What taphole process(es) does it influence

Taphole Clay Thermal Expansion

- *Measure: Volume change vs. temperature increase*
- Governed by clay composition → Expansive raw materials
- Clay Thermal Expansion influences:
    - Ramming Efficiency (is ramming done properly)
    - Seal integrity at high temperature



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Taphole Processes & Clay Features

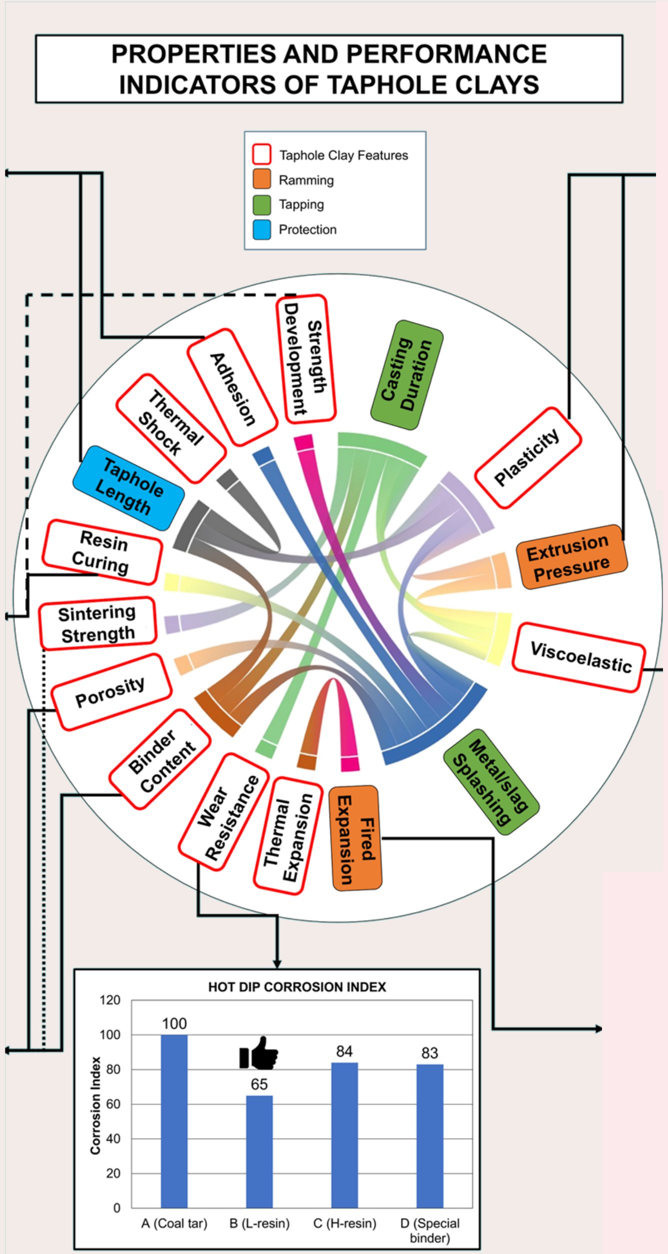
Clay Feature → What does it mean → What taphole process(es) does it influence

<u>Wear Resistance</u>

- *Measure: Hot dip testing (or high temperature microscopy)*
- Governed by clay design – raw materials (chemical), binder (physical)
- Clay Wear Resistance influences:
  - Casing duration

Figure 17. Excessive tap-hole clay bypass [BM7].

Figure 18. Controlled dosage of tap-hole clay [BM7].



Nelson, L.R. and Hundermark, R.J., 'The tap-hole' – key to furnace performance, in Furnace Tapping Conference 2014, Southern African Institute of Mining and Metallurgy, 2014.

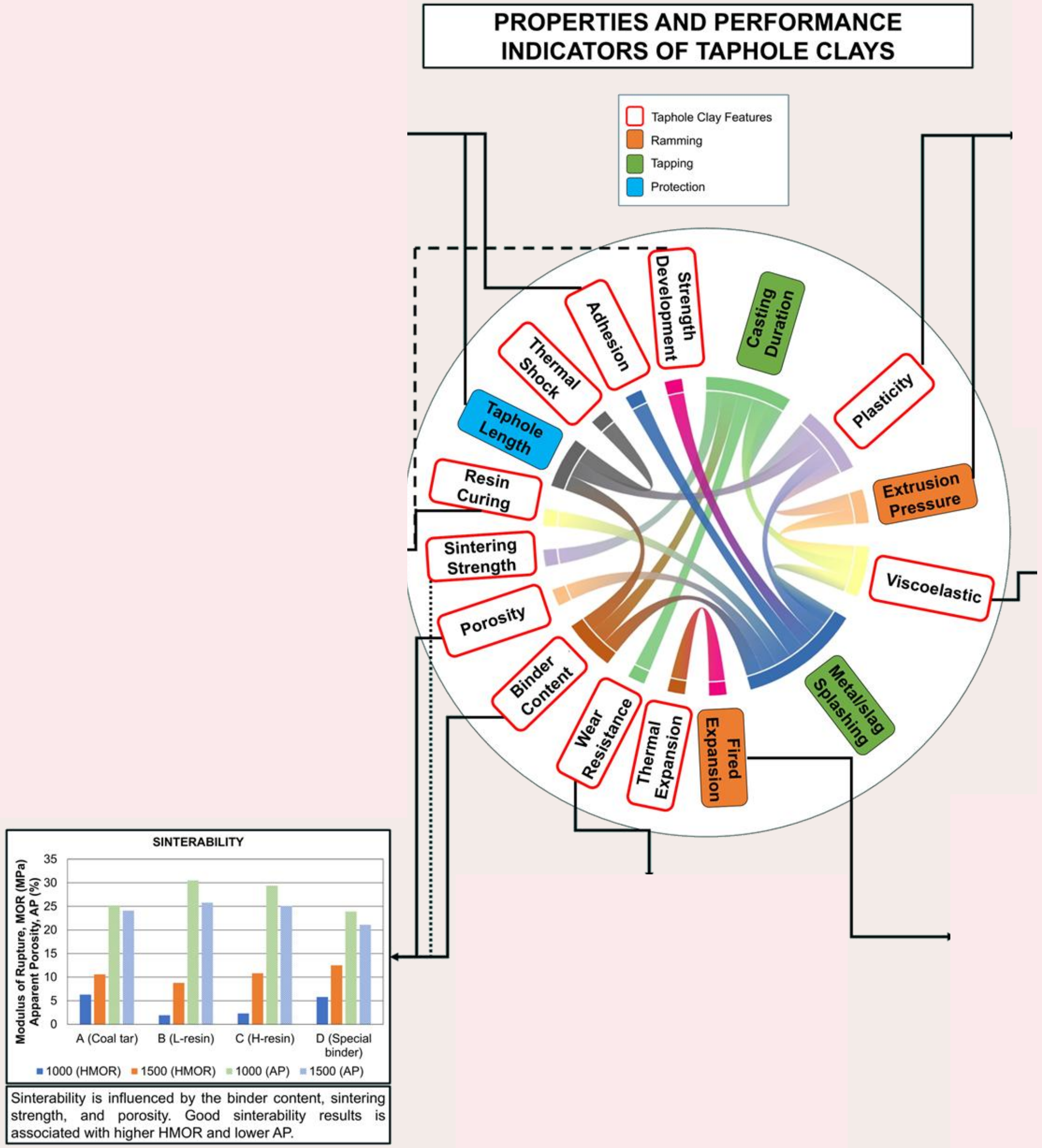
I.J. Cameron and A.M. Garbers-Craig, 'Understanding how the Binder System Influences the Properties and Process Performance Indicators of Taphole Clays', refractories WORLDFORUM 16, no. 2 (2024), 28–33.

Taphole Processes & Clay Features

Clay Feature → What does it mean → What taphole process(es) does it influence

<u>Sinterability</u>

- *Measure: Hot dip testing (or high temperature microscopy)*
- Governed by clay binder content (**quantity**), sintering strength (fluxing) and clay porosity
    - Clay porosity is a function of both raw materials and binder
- Clay Sinterability influences:
    - Molten splashing (taphole washing during tapping)
    - Casting duration (& wear)
    - Taphole length (clay strength)



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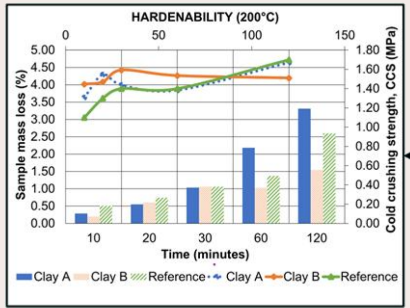
Taphole Processes & Clay Features

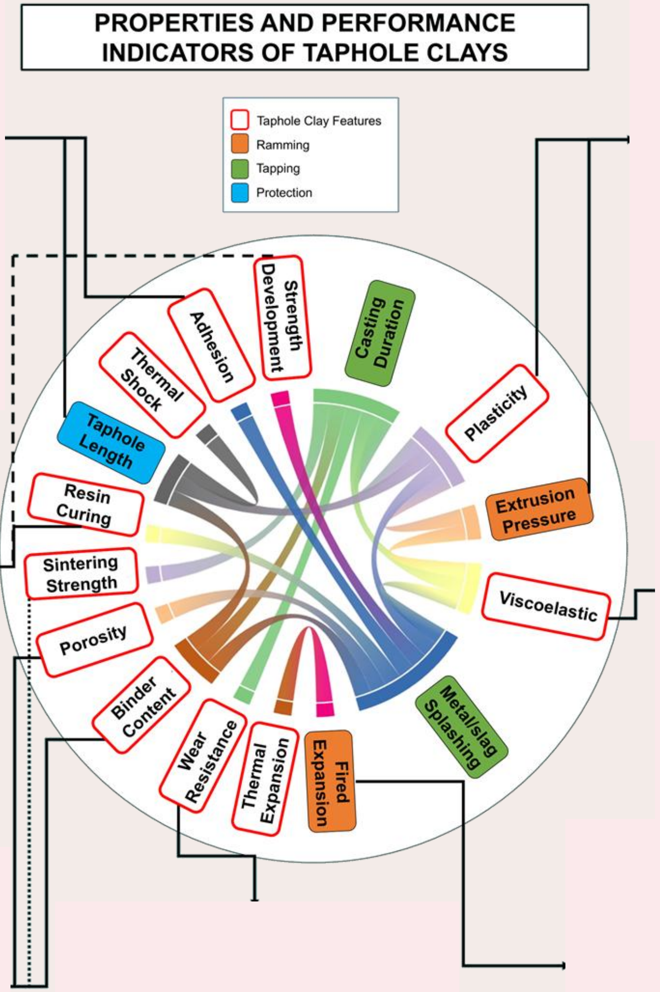
Clay Feature → What does it mean → What taphole process(es) does it influence

Hardenability (resin-containing clay/paste)

- *Measure: Cold crushing strength vs. time (incl. volatile loss)*
- Governed by binder composition – viscosity increase vs. temp.
- Clay Binder Composition influences:
  - Clay strength development (binder volatilization profile)
  - *Holding time*
  - Molten splashing



The hardenability is a measure of the strength development of the taphole clay and, with resole containing clays, is greatly influenced by the resin composition. Good hardenability results in an increase in strength. Volatilization of the binder influences strength development.



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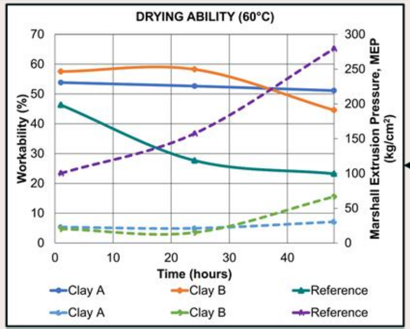
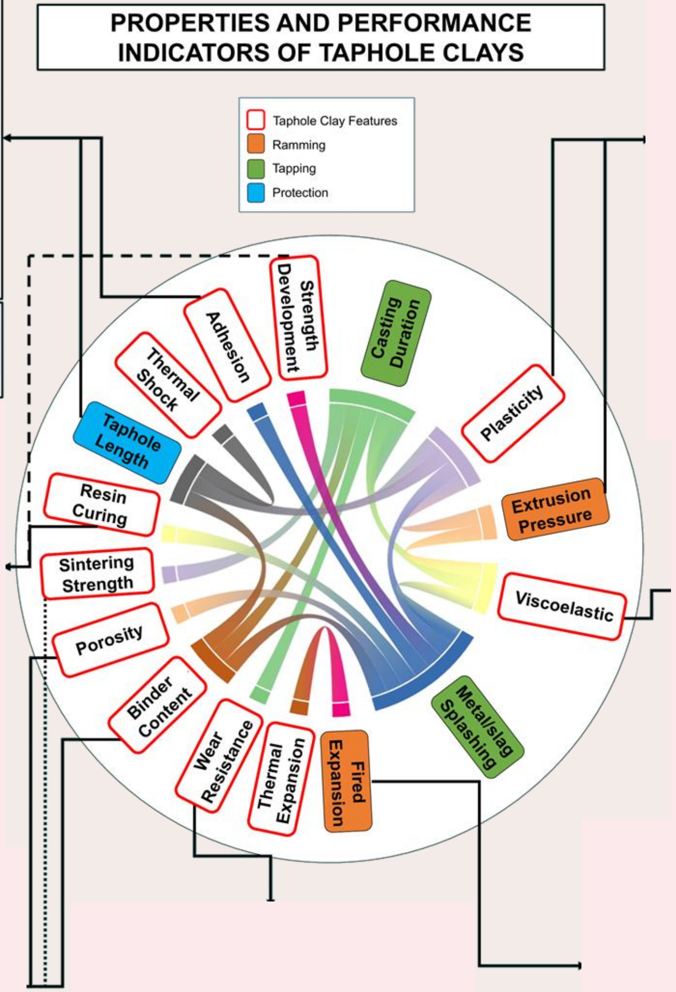
Taphole Processes & Clay Features

Clay Feature → What does it mean → What taphole process(es) does it influence



Drying-ability influences taphole length and adhesion of clay to taphole refractory. Good drying ability results in a <10% decrease in workability or MEP when heated for a extended period. Both workability and MEP should reach a plateau after 24 hours.



<u>Drying-ability</u>

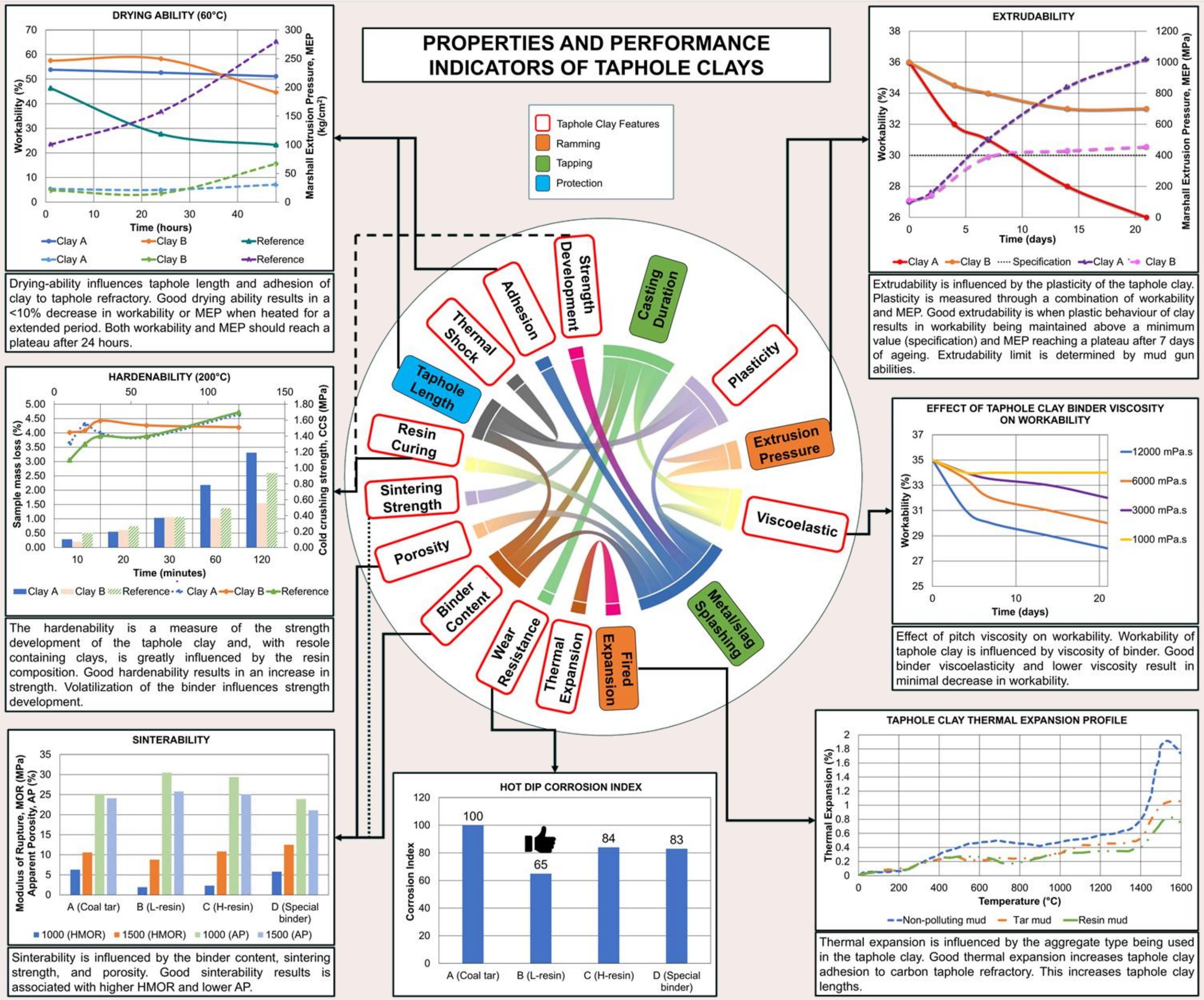
- *Workability & Extrusion Pressure ageing (60°C)*
- Governed by clay binder composition – low temp. volatiles
- How well clay adheres to tap hole refractory
- Clay Ageing influences:
    - Molten splashing
    - Tap hole length

I.J. Cameron and A.M. Garbers-Craig, ‘Understanding how the Binder System Influences the Properties and Process Performance Indicators of Taphole Clays’, refractories WORLDFORUM 16, no. 2 (2024), 28–33.

Key takeaways

How well is each process proceeding?

- **Ramming:** Mud gun → Extrusion
  - *Measure: Holding time*
  - Extrudability (23°C)
  - Drying ability (60°C)
  - Strength development (200°C)
  - Fired thermal expansion (>800°C)
  - Sinterability (>1000°C)
- **Tapping:**
  - *Measure: Drill/lancing time*
  - Hardenability
  - Tap hole length
- **Protection:**
  - *Measure: Tap hole temperature*
  - Wear resistance
  - Tap hole length



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Safety and Risk Management: Scenarios

Failure Mechanisms in Pyrometallurgical Industry

Scenario 1: Wet clay, i.e. high volatile loss clay

Tap hole closure with excessively high workability (wet) clay, causing rapid gas generation, concentrated "blowback", and a severe safety event around furnace [1]

Scenario 2: Progressive thermal accumulation in tap hole

Repeated tapping on same tap hole without sufficient recovery caused high heat flux to increase tap hole temperature, increasing risk of accelerated wear and unstable operations [1]

Scenario 3: Superheated matte / blister copper thermal hit

Loss of protective refractory or freeze lining (slag barrier) which exposed copper coolers to superheated matte, creating a high heat flux event that could drive copper cooler temperatures to failure [1]

[1] Nelson, L.R. and Hundermark, R.J., 'The tap-hole' – key to furnace performance, in Furnace Tapping Conference 2014, Southern African Institute of Mining and Metallurgy, 2014.

Scenario 1: Wet clay, i.e. high volatile loss clay

Failure Scenario

Furnace exploded after tap hole closure with a full 25-L mud gun load of excessively wet clay. The cause was excessive volatile loss from the clay, causing high turbulence in the tapping channel and a blowback. Observations were metal/matte boiling (gas introduction from clay), gas release from clay binder during tap hole closure.

Early Detection Measures

Warning Sign	Why it Matters
Clay volatile loss & rate of volatile loss	Moisture in the binder flashes to steam with very large volume expansion at elevated temperatures; release of organics from binder created turbulence in tap hole.
Tap hole volume vs. rammed volume	If mud gun theoretical volume < volume injected → bypass occurs → excessive wet material in furnace increases back pressure
Mud gun pressure fluctuations	Abnormal pressure or clay consumption → blockage, bypassing, excessive voids
Acoustic / vibration / gas monitoring at tap hole	Monitor gas release & internal agitation in tap hole

Scenario 1: Wet clay, i.e. high volatile loss clay

Main Learning

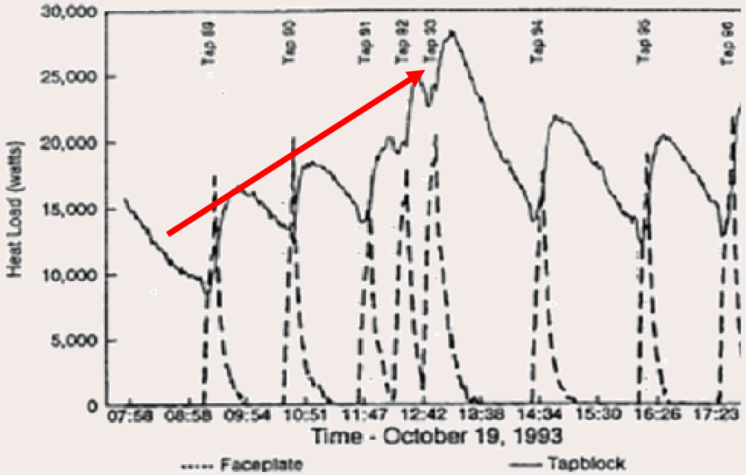
Do not treat tap-hole closure as a simple “fill the hole” activity. The detection opportunity is to combine **clay quality control**, **injected volume control**, and real-time closure response to prevent gas-driven tap-hole blows.

- Check clay volatile loss profile (LOI)
- Check workability (*& extrusion pressure*)
- Monitor tap hole conditions (gas release, vibrations) + mud gun deviations (filling, extrusion pressure)
- Monitor tap hole lengths & temperature

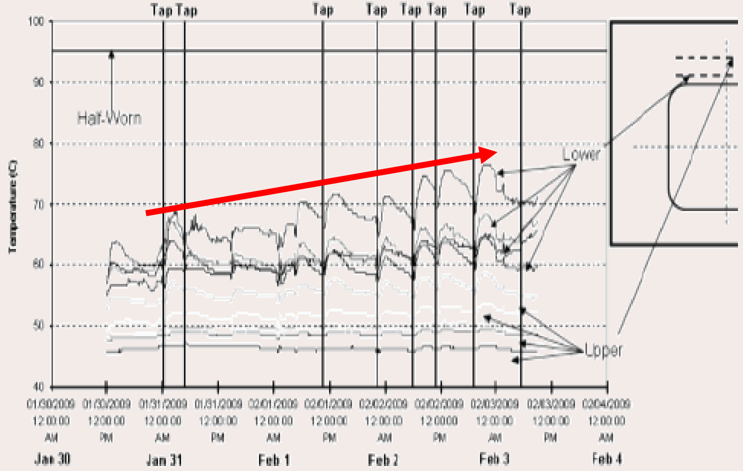
Scenario 2: Progressive thermal accumulation in tap hole

Failure Scenario

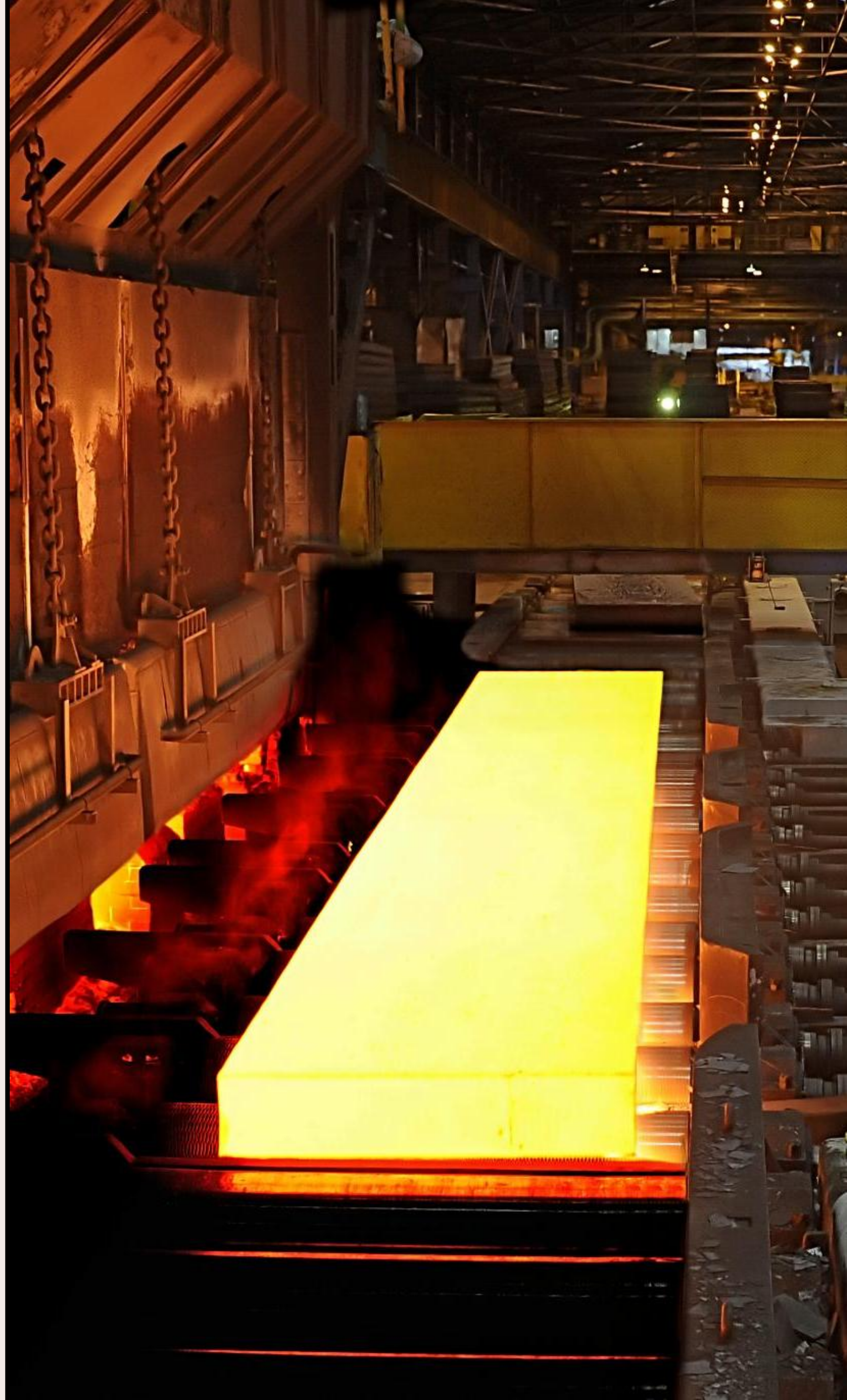
Tap hole temperature increase due to close consecutive taps causing increase refractory wear.



Ni-matte smelting [1]



PGM-matte smelting [1]



[1] Nelson, L.R. and Hundermark, R.J., 'The tap-hole' – key to furnace performance, in Furnace Tapping Conference 2014, Southern African Institute of Mining and Metallurgy, 2014.

Scenario 2: Progressive thermal accumulation in tap hole

Early Detection Measures

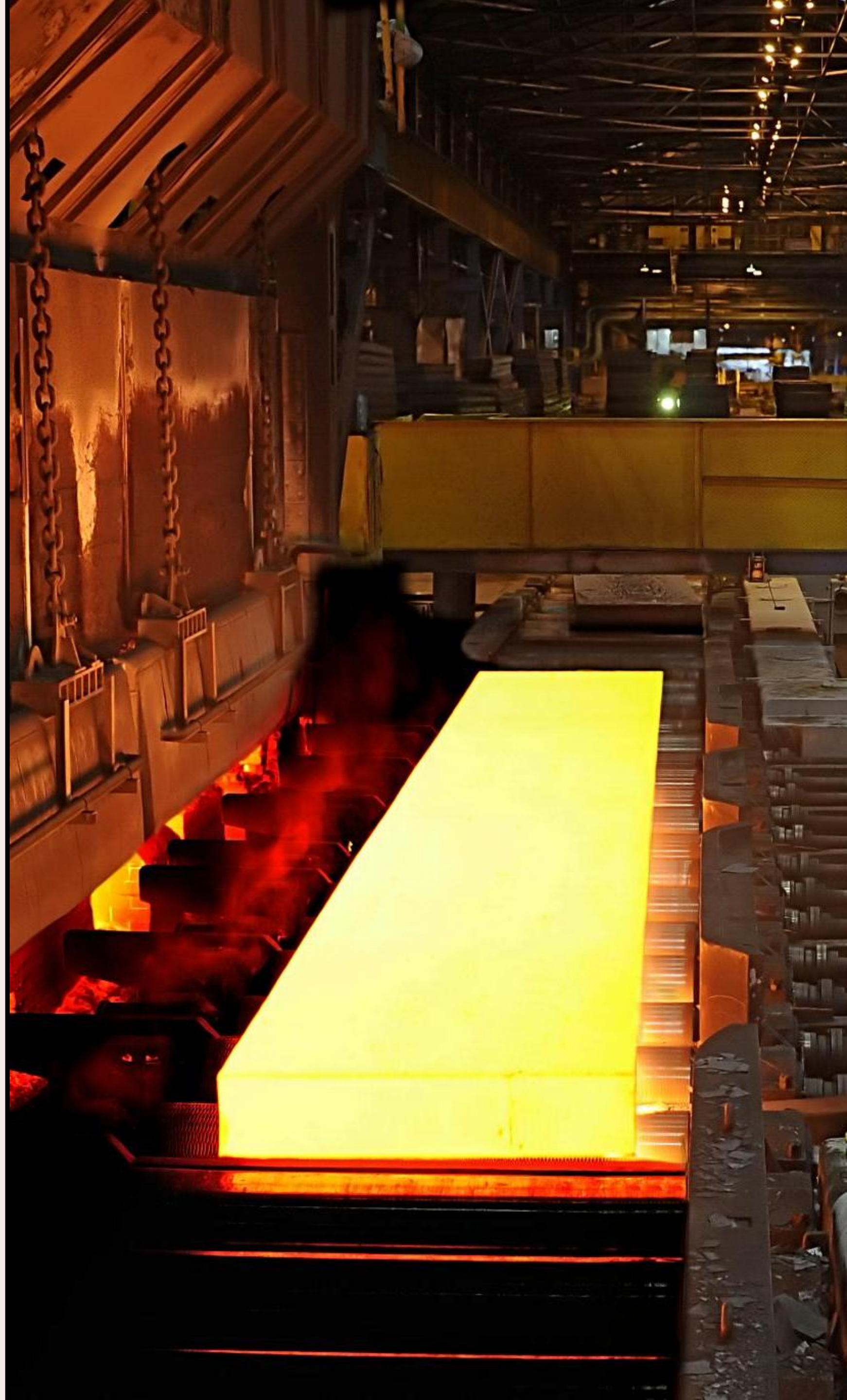
Focus on thermal trends over time not only absolute temperature.

Warning Sign	Why it Matters
Increasing baseline temperature between taps	Indicate tap block/face plate is not recovering between taps – thermal creep
Increasing maximum temperature per tap	Suggests heat accumulation & increased local wear
Delayed cooling after closure	Localized hot spots → refractory wear due to clay annulus loss/altered heat transfer path
Tap sequence deviation	Alternating tap holes allows recovery → increased operability, availability and preventive maintenance

Main Learning

Progressive bad tapping practice aids thermal increase during repeated tapping. Early detection is key:

- Flag increased tap hole temperatures
- Switching tap holes
- Extend recovery time between taps → reduced tapping intensity
- Regular tap hole inspection



Scenario 3: Superheated matte / blister copper thermal hit

Failure Scenario

Removal of slag protective layer (freeze lining) can make copper coolers susceptible to failure. Matte can have up to **four times higher superheat than slag.** If slag heat transfer is like warming your hands near a **radiator**, matte is like holding them in front of a **blowtorch** — the energy transfer is on a completely different level.

Early Detection Measures

Warning Sign	Why it Matters
Rapid temperature increase in copper cooler/tap block	Could be direct exposure of coolers to matte/loss of protective freeze lining/refractory later
Rise in cooling water temperature/ heat flux spikes	1°C rise in cooling water at 6 m^3/h corresponds to heat flux exceeding 0.5 MW/m^2 in the tapping channel…
Abnormal matte level or drainage delay	Slow tapping (tap hole wear) can delay liquid drainage and can become unsafe as copper cooler temp. increase
Loss of freeze lining behaviour	Irregular slag accretion

Scenario 3: Superheated matte / blister copper thermal hit

Main Learning

If a copper cooler is not protected by refractory or slag, a superheated matte/blister copper hit can rapidly raise the copper hot-face temperature toward melting conditions → same result as scenario 1!

A copper-cooled tap hole can look protected until the thermal barrier is gone

- Monitor rapid heat flux changes
- Wear around the tap hole (NDT/sensors)

Summary of Learnings

Scenario	Failure mode	Early detection focus	Operational response
Wet clay, i.e. high volatile loss clay	Blowback, tap-hole blow, hidden lining damage	Clay moisture/LOI, mudgun volume, pressure, gas/acoustic signals	Stop use of suspect clay, limit injection volume, verify clay preparation
Progressive thermal accumulation in tap hole	Progressive overheating, accelerated wear, unstable tapping	Tapblock/faceplate temperature trends, recovery rate, tap sequence	Alternate tap-holes, increase cooling/recovery time, inspect tapblock
Superheated matte / blister copper thermal hit	Copper cooler overheating or melting risk	Heat-flux spikes, fibre-optic/electrical temperature mapping, cooling-water ΔT	Reduce exposure, restore protective barrier, manage matte level/drainage

Integrated AI into systems monitoring

AI as a systems monitoring tool

Scenario 1: Wet clay, i.e. high volatile loss clay

- Clay batch risk: high moisture or high LOI compared with historical safe batches.
- Excess injection risk: injected clay volume far above expected tap hole channel volume.
- Pressure anomaly: mud gun pressure rises too quickly, fluctuates, or does not match normal closure profiles.
- Blowback precursor: acoustic/vibration spike during or immediately after plugging.

Scenario 2: Progressive thermal accumulation in tap hole

- Rising baseline temperature between taps.
- Higher peak temperature per tap under similar production conditions.
- Slower post-tap cooling rate, suggesting degradation or loss of protection.
- Tap sequence risk, where repeated use of one tap-hole exceeds safe thermal recovery.
- Deviation from historical thermal fingerprint, even if absolute temperature has not yet crossed a fixed alarm limit.

AI as a systems monitoring tool

Scenario 3: Superheated matte / blister copper thermal hit

- Sudden local temperature rise in a copper-cooled tap block.
- Cooling-water ΔT spike, especially if not explained by normal tapping conditions.
- Mismatch between expected and observed heat flux, suggesting loss of protective barrier.
- Slow drainage / rising matte level risk, which can become unsafe if matte encroaches near copper coolers.
- Spatial hot spot migration, indicating progressive exposure rather than normal distributed heating.

Thank You.