# Refractory Dry-Out Schedule

> How to Heat Up a New Castable Lining Without Cracking — Zone-by-Zone Heating Rates, Hold Times, and Common Failure Modes

Refractory castable dry-out is the systematic process of removing water from newly installed monolithic refractory linings through controlled temperature increase before bringing the furnace to operating temperature. All hydraulically bonded castables contain 4–6% total water after installation: 1.5–2.5% free water and 2.5–3.5% chemically bonded water in calcium aluminate hydrate crystal structures.

Industry field data indicates approximately **15% of new castable linings experience spalling during initial heat-up**, with 60% of those failures traced to the 20–400°C zone. Proper dry-out scheduling is the difference between achieving design service life and requiring emergency lining replacement before the furnace reaches operating temperature.

> **Why steam pressure is the governing constraint:** At 100°C, steam pressure = 1 bar. At 200°C = 15.5 bar. At 300°C = 85.9 bar. Fresh castable tensile strength is only 5–8 MPa before ceramic bonding develops above 600°C. If heating is too rapid, internal vapor pressure exceeds tensile strength → explosive spalling.

## Temperature Zone Overview

| Zone | Range | Primary Risk | Key Event |
|---|---|---|---|
| **Zone 1** | 20–200°C | Highest — explosive spalling | Free water evaporation; peak moisture + minimum strength |
| **Zone 2** | 200–600°C | Moderate | Calcium aluminate hydrate decomposition ($CAH_{10}$ → $C_2AH_8$ → $C_3AH_6$) |
| **Zone 3** | 600–1000°C | Low | Ceramic bond formation; mullite sintering; hot strength development |

## Heating Rate and Hold Time Schedule by Castable Type

| Temperature Range | Conventional Castable (15–25% cement) | LCC (3–8% cement) | ULCC (<3% cement) |
|---|---|---|---|
| 20 → 110°C | 10°C/h · hold 6h at 110°C | 10°C/h · hold 6h at 110°C | 15°C/h · hold 4h at 110°C |
| 110 → 200°C | 10°C/h · hold 4h at 200°C | 10°C/h · hold 4h at 200°C | 12°C/h · hold 2h at 200°C |

| Temperature Range | Conventional Castable (15–25% cement) | LCC (3–8% cement) | ULCC (<3% cement) |
|---|---|---|---|
| 200 → 600°C | 15–20°C/h | 20°C/h | 25°C/h |
| 600 → 1000°C | 30–50°C/h · soak 6h at 1000°C | 30–50°C/h · soak 6h at 1000°C | 40–50°C/h · soak 4h at 1000°C |
| 1000°C → Service Temp | 50–100°C/h | 50–100°C/h | 50–100°C/h |
| **Total time to 1000°C** | **60–72 hours** | **50–60 hours** | **42–50 hours** |

**Schedule Adjustments for Special Conditions**

- **Thick linings (>200mm):** Reduce all heating rates by 25–30%; add 2h holds at 300°C and 600°C
- **Large monolithic masses (>5 tons):** Reduce heating rates by 30–40%; thermal gradients in large masses create internal stress
- **Winter conditions (ambient <10°C):** Extend hold at 110°C to 8 hours; higher free water content expected
- **High humidity curing (>80% RH):** Extend 20–200°C zone by 20%; absorbed ambient moisture increases total water

## Zone 1 Detail: Free Water Evaporation (20–200°C)

This zone carries the highest spalling risk: maximum water content, lowest material strength (tensile 5–8 MPa), and steeply increasing steam pressure. The 110°C hold is the most critical single step in the entire dry-out process — it allows bulk free water to boil off at atmospheric pressure before temperature rises further.

> **Hard limit:** Exceeding 15°C/hour in the 100–200°C zone causes spalling in 80% of cases for conventional castable. Even ULCC should not exceed 20°C/hour. The 6–8 hours saved by faster heating are not worth the risk of complete lining failure.

## Zone 2 Detail: Chemically Bonded Water Release (200–600°C)

Calcium aluminate hydrates decompose in sequence as temperature rises:

- 200–300°C: $CAH_{10}$ (calcium aluminate decahydrate) → releases 10 $H_2O$ per formula unit
- 300–400°C: $C_2AH_8$ (dicalcium aluminate octahydrate) → releases 8 $H_2O$
- 400–600°C: $C_3AH_6$ (tricalcium aluminate hexahydrate) → releases 6 $H_2O$; initial ceramic phase conversion begins

Risk is lower than Zone 1 because water releases gradually from crystal decomposition. For linings >150mm, add a 2–4h hold at 400°C to allow interior temperature equilibration.

## Zone 3 Detail: Ceramic Bond Formation (600–1000°C)

Above 600°C, the castable transitions from hydraulic bonding to ceramic bonding. Mullite ($3Al_2O_3 \cdot 2SiO_2$) forms from clay-bonded components; calcium aluminate forms from cement residues. The 4–6 hour soak at 1000°C is essential — without it, the castable achieves only 70–80% of potential hot strength.

## 5 Common Dry-Out Errors

> **Error 01 — Skipping the 110°C hold:** Bulk water superheats above boiling point; steam pockets form and cause surface spalling. The 4–6 hour hold at 110°C is non-negotiable.

> **Error 02 — Insufficient curing before dry-out:** Beginning heat-up 12–16 hours after casting. Hydration is incomplete; material strength is insufficient for any thermal stress. Minimum 24h cure at ambient temperature; 48–72h preferred for thick sections.

> **Error 03 — Exceeding 15°C/hour in 100–200°C zone:** The #1 cause of spalling failures in the field. Time savings of 6–8 hours cost 10× more in emergency lining replacement.

> **Error 04 — Controlling from furnace atmosphere temperature:** Hot face temperature can be 100–200°C higher than furnace atmosphere in radiant heating setups. Monitor castable hot face directly with surface thermocouples or IR pyrometer.

> **Error 05 — Omitting the 1000°C soak:** Incomplete ceramic bond formation; castable achieves only 70–80% of potential hot strength. Interior sections fail to reach temperature equilibrium.

## Monitoring and Documentation Requirements

### Essential Monitoring Equipment

- Surface thermocouples: Type K attached to castable hot face. Minimum 3 locations for small furnaces; 5–8 for large installations. Position at thinnest and thickest sections.
- Data logger: Record temperature every 5–10 minutes. Manual recording every 30–60 minutes is the minimum acceptable.
- IR pyrometer: Non-contact spot-checking for hot face uniformity; critical for detecting localized hot spots.

### Temperature Uniformity Requirements

- Maximum differential: ≤50°C between hottest and coolest zones during 20–400°C range; ≤100°C acceptable above 600°C
- Heating method: Low-velocity hot air circulation preferred over direct flame impingement
- Thick sections lag thin sections by 20–40°C; always control based on the thickest section

### Documentation Checklist

1. Castable identification: product name, batch number, supplier, installation date, curing duration
2. Temperature-time curve: all monitoring points vs elapsed time, with heating rate calculations per zone
3. Hold period verification: time at each hold temperature with stability confirmation (±10°C)
4. Visual observations at each hold: steam emission, cracking, spalling, or discoloration
5. Completion certification: signed by responsible engineer, filed with furnace maintenance records

**Need a customized dry-out curve?**
Send your castable type, lining thickness, and furnace heating capability. Our engineers provide a temperature-time schedule with zone-specific heating rates and hold point recommendations.

Full technical guide: vuulcanrefractories.com/technical-center/refractory-dry-out-schedule/
Engineering inquiry: vuulcanrefractories.com/contact/