

Refractory Properties Comparison: What Do CCS, PLC, Thermal Conductivity, and Porosity Actually Tell You?

Every refractory data sheet lists the same numbers: Cold Crushing Strength, Permanent Linear Change, thermal conductivity, apparent porosity. Engineers compare them in tables, procurement teams use them to rank suppliers, and maintenance managers reference them during shutdown planning.

But here's the problem — **these numbers are routinely misinterpreted**. A higher CCS doesn't necessarily mean a better refractory. A lower porosity isn't always an advantage. And thermal conductivity measured in the lab may tell you very little about how that material will actually perform inside your furnace.

In this guide, we break down what each of these four core properties actually reveals about refractory performance — and, just as importantly, what it doesn't. If you specify, evaluate, or maintain refractory linings, understanding these nuances will help you avoid costly material selection mistakes.

Porosity: the property that governs everything else

If you could only look at one number on a data sheet, porosity would give you the most information. That's because it directly influences corrosion resistance, thermal shock behavior, permeability, thermal conductivity, and mechanical strength — virtually every other property that matters in service.

What the number actually represents

Apparent Porosity (AP) measures the volume of **open, interconnected pores** as a percentage of total volume. These are the pores that liquids and gases can enter. Total (true) porosity also includes sealed, closed pores that are inaccessible from the surface.

The distinction matters. Two bricks with identical apparent porosity but different total porosity will behave differently under thermal shock — because closed pores contribute to crack arrest without providing pathways for corrosive infiltration.

How porosity controls corrosion resistance

Open pores act as pathways — think of them as a network of channels that allow molten slag, glass, or metal to penetrate into the refractory body. The deeper the penetration, the more destructive the corrosion, because **reactions occur not just at the hot face but throughout the infiltrated zone**.

In our experience, the relationship is roughly linear within typical ranges: between 12% and 16% AP, the rate of slag corrosion increases proportionally with each percentage point of porosity.

But volume alone doesn't tell the whole story. **Pore size distribution is equally critical**. A material with fine pores (below 1–5 μm) resists infiltration far better than one with the same total porosity but coarser pores. The reason is capillary pressure — finer pores generate higher resistance to liquid ingress.

The practical implications are significant. Critical pore diameters below which specific melts cannot penetrate are approximately:

Melt type	Critical pore diameter
Steel	~30 μm
Cast iron	~5 μm
Aluminum	~0.5 μm

This explains why aluminum contact applications demand extremely fine-pored, low-porosity refractories, while steelmaking applications can tolerate somewhat coarser structures.

The porosity–thermal shock trade-off

Here's where it gets counterintuitive. **Higher porosity generally improves thermal shock resistance** — the exact opposite of its effect on corrosion resistance.

Pores act as crack stoppers through several mechanisms:

- **Crack tip blunting.** When a propagating microcrack encounters a pore, the sharp crack tip — an extreme stress concentrator — is replaced by the rounded surface of the pore. This can dramatically reduce stress intensity and halt further crack growth.
- **Crack deflection and branching.** Pores force cracks to change direction or split into multiple smaller branches. Each deflection consumes additional energy, increasing the material's effective toughness.
- **Lower elastic modulus.** A more porous body is less stiff. Lower stiffness means lower thermal stresses for a given temperature change — the material can "flex" rather than fracture.
- **Reduced stored elastic energy.** Dense, high-strength refractories accumulate large amounts of elastic strain energy during heating. That stored energy is the driving force for rapid, destructive crack propagation. Porosity reduces this energy reserve.

This is exactly why insulating firebricks — with porosities of 45–85% — are essentially immune to thermal shock damage, while dense, low-porosity refractories can crack catastrophically after a single rapid temperature change.

The design compromise

Every refractory engineer faces the same dilemma: **lower porosity for corrosion resistance, or higher porosity for thermal shock resistance?** The answer depends entirely on which wear mechanism dominates in your specific application.

In a cement kiln burning zone, where chemical attack by alkali-rich clinker liquid is the primary threat, you want low porosity. In a steel ladle that undergoes rapid thermal cycling with every heat, you need enough porosity to survive the shock. Getting this balance wrong is one of the most common — and most expensive — material selection errors.

Cold Crushing Strength: the most misunderstood number on the data sheet

CCS is the maximum compressive load a refractory sample can withstand at room temperature before it fails. It is also, arguably, the most overvalued property in refractory specification.

What CCS actually tells you

CCS is primarily a **quality control tool**. It indicates whether the material was fired at the correct temperature during manufacture, whether sintering has progressed adequately, and whether the bond system — hydraulic, chemical, or ceramic — has developed as intended.

In other words, it tells you about manufacturing consistency. A batch of bricks with CCS significantly below the specification probably has a production issue. That is genuinely useful information.

Why higher CCS doesn't mean "better"

There is a persistent myth in the industry that a refractory with a higher CCS is inherently superior. **This is misleading, and in some cases the opposite is true.**

The core problem: CCS is measured at ambient temperature. A refractory's operating environment is 800°C, 1200°C, 1500°C or higher. The material's behavior at room temperature may bear little resemblance to its behavior at working temperature.

Specifically:

Excessive CCS can indicate high glassy phase content. Glass is strong and rigid at room temperature — which produces impressive CCS numbers. But glass softens progressively with increasing temperature. A refractory rich in glassy phase may show excellent CCS at 20°C but deform readily under load at 1100°C. The result is creep — a slow, irreversible dimensional change under sustained stress at high temperature that can collapse lining geometry and close critical clearances.

Very high CCS often correlates with brittleness. Extremely strong, rigid materials have limited capacity to accommodate thermal and mechanical stresses. Under cyclic temperature changes, they are prone to catastrophic fracture and spalling rather than controlled microcracking.

CCS says nothing about hot strength. For predicting in-service mechanical performance, **Hot Modulus of Rupture (HMOR)** and **Refractoriness Under Load (RUL)** are far more informative. HMOR measures bending strength at the actual operating temperature. RUL measures resistance to deformation under a constant load as temperature increases. Both give direct insight into whether the material will maintain its structural integrity where it actually matters — inside the furnace.

What CCS is genuinely useful for

CCS reliably predicts whether a refractory will survive the mechanical stresses of **transport, handling, and installation**. A brick needs enough compressive strength to resist stacking loads, forklift impacts, and the forces of bricklaying. For this purpose, CCS is an appropriate and necessary specification.

There is also an empirical relationship between CCS and Modulus of Rupture (Cold MOR): $CCS \approx k \times MOR^{1.5}$. This can be useful for cross-checking test results, but it does not extend to hot properties.

The practical takeaway

When reviewing a data sheet, resist the instinct to equate higher CCS with better quality. Instead, ask: what are the **dominant stresses in my specific application** — compressive, thermal, chemical? Then look at the properties that directly measure resistance to those stresses. CCS tells you whether the material was properly manufactured. It does not tell you how long your lining will last.

Permanent Linear Change: predicting whether your joints will hold

Permanent Linear Change (PLC) — also known as reheat change or permanent dimensional change after heating — measures the irreversible change in dimensions that occurs when a refractory is heated to a specified temperature and then cooled back to ambient.

What PLC reveals about manufacturing

PLC exposes whether a refractory was brought to a **stable equilibrium condition** during manufacture. If a brick is fired at a lower temperature than its eventual service temperature, the chemical reactions and sintering processes that weren't completed in the kiln will continue inside your furnace.

That continued reaction means the material is still changing dimensions while it's in your lining — and once it cools down, it won't return to its original size.

PLC is not the same as thermal expansion

This is a critical distinction that is often confused, even by experienced engineers.

Reversible Thermal Expansion (RTE) is the temporary increase in dimensions that occurs while a material is hot. It is a purely physical process — atoms vibrate more at higher temperatures, the crystal lattice expands, and the material grows. When it cools, it returns to its original dimensions. RTE is what you design expansion joints for.

Permanent Linear Change (PLC) is what remains after the material has cooled completely. It's the permanent footprint that high-temperature exposure leaves on the material's structure. PLC results from:

- Further sintering and pore elimination (causes shrinkage)
- Phase transformations and chemical reactions at service temperature — such as mullite or spinel formation (can cause expansion or shrinkage depending on the reaction)
- Decomposition of binders or evolution of gases

Think of it this way: **RTE is the material breathing with temperature — it always returns to its starting point. PLC is a permanent change in the material's DNA after exposure to service conditions.**

Why PLC matters for lining integrity

Negative PLC (shrinkage) is the more common concern. When a refractory shrinks permanently during service, joints open. Open joints allow flames, hot gases, or corrosive liquids to bypass the working lining and

attack the backup insulation or the steel shell. In severe cases, this can lead to shell hot spots, accelerated backup degradation, and unplanned shutdowns.

Positive PLC (expansion) is sometimes designed in deliberately. In vessel linings like steel ladles, a controlled positive PLC creates a tight ring clamp as the bricks grow slightly during the first heating cycles. This self-tightening effect seals joints and prevents metal penetration — a critical requirement in steelmaking applications. Some materials based on "bloating clays" or spinel-forming compositions are engineered specifically for this purpose.

How PLC affects furnace construction

The interplay between RTE and PLC drives several critical design decisions:

Expansion joints must accommodate RTE — the reversible thermal "breathing" of the lining during every operating cycle. Undersized joints lead to compressive failure, spalling, and in extreme cases, distortion of the steel shell. Overly generous joints allow hot gas bypass.

Long-term joint integrity depends on PLC. Even if expansion joints are correctly designed for RTE, excessive negative PLC will progressively open working joints over the campaign, degrading lining performance over time.

Mortar joints play a compensating role. Properly formulated mortar is slightly compressible, absorbing up to half of the brickwork's reversible thermal expansion. In large-scale constructions like coke oven batteries — where classical expansion joints are impractical — highly plastic mortars are used to accommodate the full thermal expansion of the wall.

The practical takeaway

When specifying refractories, always check that PLC was measured at a temperature **comparable to your actual operating conditions**. PLC data at 1000°C is irrelevant if your application runs at 1500°C. And remember — a small, controlled positive PLC can be an advantage in some vessel designs, while negative PLC is almost always undesirable.

Thermal Conductivity: the number that changes with everything

Thermal conductivity (k or λ) quantifies the rate of heat transfer through a material. In refractory engineering, it determines how effectively a lining acts as an **insulator** (to conserve energy and protect the shell) or as a **conductor** (to remove heat and cool the lining's hot face).

What the number tells you

At its most basic, thermal conductivity is the foundation for every heat balance calculation in furnace design. It determines lining thickness, shell temperature, heat loss, and energy consumption. Get the value wrong, and the entire thermal design falls apart.

But here's the challenge: **thermal conductivity is not a fixed material constant**. It changes with temperature, atmosphere, and measurement method — sometimes dramatically.

How temperature changes everything

Dense and porous refractories respond to temperature in opposite ways:

Dense refractories: Conductivity **decreases** as temperature increases. The mechanism is phonon scattering — as atoms vibrate more intensely at higher temperatures, they interfere more with heat conduction through the crystal lattice.

Insulating and lightweight refractories: Conductivity **increases** with temperature. At high temperatures, radiation across the large internal pores becomes the dominant heat transfer mechanism, overwhelming the solid-phase conduction that dominates at lower temperatures.

This crossover behavior means that an insulating refractory that performs well at 600°C may provide significantly less insulation at 1200°C — a fact that must be accounted for in multi-layer lining design.

The atmosphere effect that most engineers overlook

Thermal conductivity depends not only on the solid material but also on **the gas filling its pores**. This is particularly relevant for porous refractories.

An aluminosilicate refractory in a hydrogen atmosphere has **significantly higher thermal conductivity** than the same material in air. Hydrogen's thermal conductivity is approximately 7× that of nitrogen. In applications where hydrogen-rich gases are present — certain heat treatment furnaces, direct reduction ironmaking — standard conductivity data measured in air will substantially underestimate actual heat losses.

Why measurement method matters

Two standard methods exist for measuring thermal conductivity, and they can give **results that differ by 15–25%**:

Method	Principle	Typical application
Calorimeter (steady-state)	Measures heat flow after temperature equilibrium	Reference method for furnace design; measures average across a temperature gradient
Hot Wire (transient)	Measures temperature response to a rapid heat pulse	Faster measurement; gives point values at specific temperatures

The discrepancy arises from fundamental differences in how these methods work. The calorimeter measures conductivity as an average across the temperature gradient within the sample, while the hot wire method captures a value at a specific temperature. Additionally, the hot wire method sends heat radially, while the calorimeter sends it linearly — for anisotropic materials, this produces different results.

In practice, furnace designers typically prefer calorimeter (steady-state) data. When only hot wire data is available, correction factors of **0.7–0.8** are commonly applied to align with design expectations.

Practical implications for lining design

When specifying refractories for a new lining or evaluating insulation performance:

- **Always check the measurement method.** Data sheets don't always specify it. If the conductivity values look surprisingly low for a dense material, they may be steady-state values. If they look high for an insulating material, they may be hot wire values.
- **Use temperature-specific values.** A single conductivity number at 1000°C is insufficient for a lining that sees a temperature gradient from 1500°C at the hot face to 150°C at the shell. Multi-point data across the operating range is essential.
- **Account for atmosphere.** If your process involves reducing gases, hydrogen, or steam, standard air-measured data may underestimate your actual heat losses.
- **Consider the effect of aging.** Slag infiltration, sintering, and chemical reactions during service all alter pore structure — and therefore conductivity. A lining's thermal performance in its first month may differ considerably from its performance after a year.

How these four properties interact

No refractory property exists in isolation. The four properties discussed here form an interconnected system, and understanding those connections is what separates effective material selection from data sheet comparison.

Porosity is the common thread

Porosity directly influences all other three properties:

As porosity increases...	CCS	PLC (tendency)	Thermal conductivity
Effect	Decreases	Shrinkage tendency may increase (more volume to sinter)	Decreases (more insulating)
Trade-off gained	Better thermal shock resistance	—	Better energy efficiency
Trade-off lost	Lower mechanical strength	Potential joint instability	Less protection by conductive cooling

The CCS–thermal shock paradox

Very high CCS typically means very low porosity and high stiffness — both of which **reduce** thermal shock resistance. The strongest material on the shelf may also be the most vulnerable to rapid temperature changes. When cyclic thermal loading is part of your operating reality, moderate CCS is often the wiser specification.

PLC and conductivity co-dependency

As a material undergoes permanent dimensional change during service — whether sintering (shrinkage) or phase transformation (expansion) — its pore structure changes. Sintering reduces porosity, which increases

thermal conductivity. The lining becomes a less effective insulator over time. This is why thermal survey data from year one of a campaign should not be used to predict shell temperatures in year three without accounting for this progression.

Key takeaways

- **Porosity** is the most informative single property — it predicts corrosion resistance, thermal shock behavior, and thermal performance. But pore size distribution matters as much as total pore volume.
 - **CCS** is a manufacturing quality indicator, not a service performance predictor. High CCS can signal excessive glassy phase and brittleness. For in-service strength, look at HMOR and RUL.
 - **PLC** reveals whether a material has reached dimensional equilibrium. Always verify that test temperatures match your operating conditions. Negative PLC opens joints; controlled positive PLC can seal them.
 - **Thermal conductivity** varies with temperature, atmosphere, and measurement method. Use steady-state values for furnace design, apply correction factors to hot wire data, and account for process atmosphere effects.
 - **No property should be evaluated in isolation.** Material selection is about finding the right balance among competing requirements — and that balance is different for every application.
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Need help interpreting data sheet values for your specific application? PCO's technical team can help you evaluate material properties in the context of your operating conditions, wear mechanisms, and performance targets. Reach out at technical@pco-refractories.com.

Related PCO solutions:

- [Refractory material selection support →] PCO's R&D laboratory and engineering team provide application-specific material recommendations based on your operating conditions and dominant wear mechanisms.
 - [Lining condition assessment →] PCO Serwis offers on-site lining inspection during planned shutdowns — including dimensional measurements that reveal actual PLC behavior in service.
 - [Custom formulations →] PCO's own R&D center develops tailored refractory compositions when standard products don't match the property balance your application requires.
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Image suggestions:

1. alt="Diagram showing the relationship between porosity, corrosion resistance, and thermal shock resistance in refractory materials" — A conceptual diagram illustrating the trade-off: as porosity increases, corrosion resistance decreases while thermal shock resistance improves.
2. alt="Table comparing critical pore diameters for steel, cast iron, and aluminum melt penetration into refractory pores" — Visual version of the pore diameter table for social media sharing.
3. alt="Cross-section micrograph showing crack tip blunting at a pore in a refractory microstructure" — Microphotograph (if available from PCO lab) or schematic showing how pores arrest crack propagation.
4. alt="Graph showing opposite thermal conductivity trends for dense and insulating refractories as temperature increases" — Chart showing dense materials' conductivity decreasing and insulating materials' conductivity increasing with temperature.

LinkedIn post proposal:

Your data sheet says CCS is 85 MPa.

Your competitor's says 70 MPa.

The 85 MPa brick wins. Right?

Not necessarily.

That higher CCS might actually mean MORE glassy phase in the structure — which makes it rigid and strong at room temperature, but prone to creep and deformation at 1200°C.

Four numbers dominate every refractory data sheet: CCS, PLC, thermal conductivity, porosity.

Most engineers compare them. Few truly understand what each one does — and doesn't — reveal about service performance.

For example:

- Higher porosity IMPROVES thermal shock resistance (pores stop cracks)
- CCS predicts handling strength, not furnace performance
- Thermal conductivity can shift 15–25% depending on how it was measured
- PLC test temperature must match YOUR operating temperature — or it's meaningless

We wrote a practical guide breaking down all four properties.

Link in comments.

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