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Properties of Refractories

Physical Testing - Why

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- Quality Control
- Characterisation
- Product Development
- Problem solving
- Product Selection

Physical Testing

Quality Control

- Standard routine tests that are quick and easy for Quality Control
- Results can be determined either during production or shortly afterwards
- "Control Tests"

Routine Refractory Testing

Density / Porosity	EN 993-1
CCS	ISO 10059-2
Cold MOR	EN 993-6
Hot MOR	EN 993-7
Particle Size Analysis	EN1402-3
Flow Properties / Setting Time	ISO 1927-4
PLC	EN 993-10
Thermal Expansion	EN 993-19

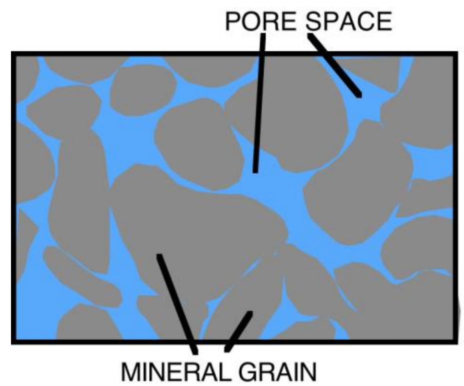
Bulk Density and Apparent Porosity

EN 993-1 Determination of bulk density and apparent porosity

Bulk Density - The ratio of the mass of the dry material of a porous body to its bulk volume

Bulk Volume – The sum of the volumes of the solid material, the open pores and closed pores in a porous body

Apparent Porosity – The ratio of the total volume of the open pores in a porous body to its bulk volume, expressed a percentage of the bulk volume



Bulk Density and Apparent Porosity

EN 993-1 Determination of bulk density and apparent porosity

Apparatus :

Evacuating Equipment

Balance

Bulk Density and Apparent Porosity

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EN 993-1 Determination of bulk density and apparent porosity

Measurements :

m_1 = mass of dry test piece

m_2 = apparent mass of immersed test piece

m_3 = mass of soaked test piece

ρ_{liq} = Density of immersion liquid

Bulk Density and Apparent Porosity

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EN 993-1 Determination of bulk density and apparent porosity

Calculations :

Bulk Density = $$\frac{m_1 \times \rho_{liq}}{m_3 - m_2}$$

Apparent Porosity = $$\frac{m_3 - m_1}{m_3 - m_2} \times 100\%$$

m_1 = mass of dry test piece

m_2 = apparent mass of immersed test piece

m_3 = mass of soaked test piece

ρ_{liq} = Density of immersion liquid

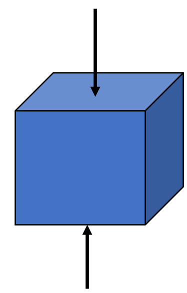
Cold Crushing Strength

ISO 10059-2 Determination of cold compressive strength (CCS)

The maximum load (applied under specified conditions at room temperature) divided by the area over which the load is applied, that a refractory product will withstand before failure occurs.

$$\text{C.C.S.} = \frac{\text{Maximum Force}}{\text{Cross Sectional Area}}$$

Units N / mm^2



Cold Crushing Strength

Cold Compression Testing Machine

The machine shall be capable of increasing the stress rate at 0.2MPa/s until the test piece is unable to support the load.

The machine should be capable of measuring the load exerted on the test piece to within

+/- 2%

Cold Crushing Strength

Sample Loading

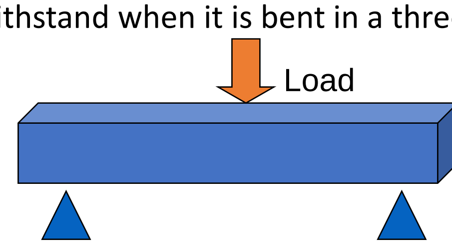
Failed Sample

Modulus of Rupture (Bend Strength)

EN 993-6 / EN 993-7 Determination of modulus of rupture at ambient and elevated temperatures

Definition :

The maximum transverse stress that a prismatic test piece of specified dimensions can withstand when it is bent in a three point loading device.



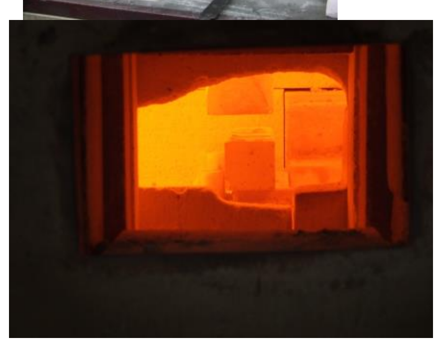
Modulus of Rupture (Bend Strength)

Modulus of rupture is the ratio of the bending moment at the point of failure (M_{max}) to the moment of resistance W (the section modulus) and is calculated from the following equation :

$$MOR = \frac{M_{max}}{W} = \frac{3 \times F_{max} L_s}{2 \quad bh^3}$$

Maximum load (Failure Load) in flexure is actually recorded
Flexural Stress is calculated from load and test piece dimensions
Units N/mm^2 (MPa)
Can be measured at ambient or elevated temperatures.

Modulus of Rupture (Bend Strength)



Permanent Linear Change (PLC)

BSEN 993-10 Determination of permanent change in dimensions on heating (PLC)

Definition :

The expansion or contraction that remains in a shaped refractory that is heated to a specified temperature for a specified time and ten cooled to ambient temperature.

Permanent Linear Change (PLC)

BSEN 993-10 Determination of permanent change in dimensions on heating (PLC)

Equipment :

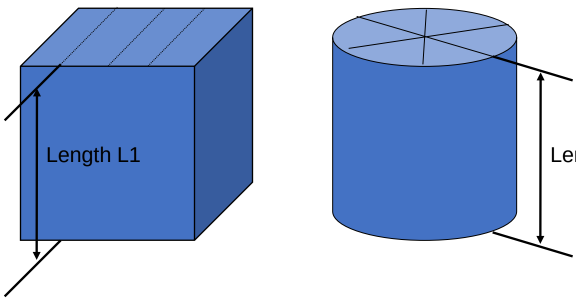
- Furnace
- Vernier Calipers

Test Pieces :

- Rectangular Prism 50 x 50 x 60mm
- Cylinders 50mm diameter x 60mm height

Permanent Linear Change (PLC)

BSEN 993-10 Determination of permanent change in dimensions on heating (PLC)



Length of test piece measured in 3 positions and positions marked.

Permanent Linear Change (PLC)

BSEN 993-10 Determination of permanent change in dimensions on heating (PLC)

Heating Rates

Test Temperatures up to 1250^{0}C	Ambient to 50C below test temperature Last 50C	5-10^{0}C/min 1-5^{0}C/min
Test Temperatures above 1250^{0}C	Ambient to 1200^{0}C below test temperature Last 50^{0}C	5-10^{0}C/min 2-5^{0}C/min

Thermal Expansion

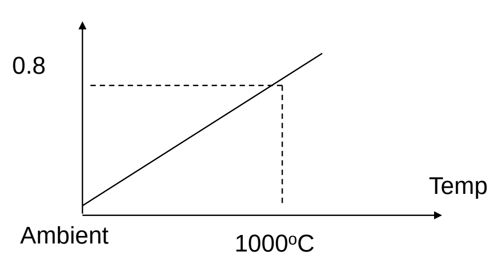
The proportional extension which occurs when a material is heated.

A test piece is heated at a specified uniform rate and its change in <u>length</u> and temperature measured either continuously or at regular frequent intervals.

Thermal Expansion

Thermal Expansion

Results can be plotted graphically.



Or quoted as a mean co-efficient of expansion per unit of temperature up to a specified maximum temperature.
The co-efficient of thermal expansion up to 1000ºC would be 0.0008 i.e. it would expand 0.0008% for every ºC temperature increase.

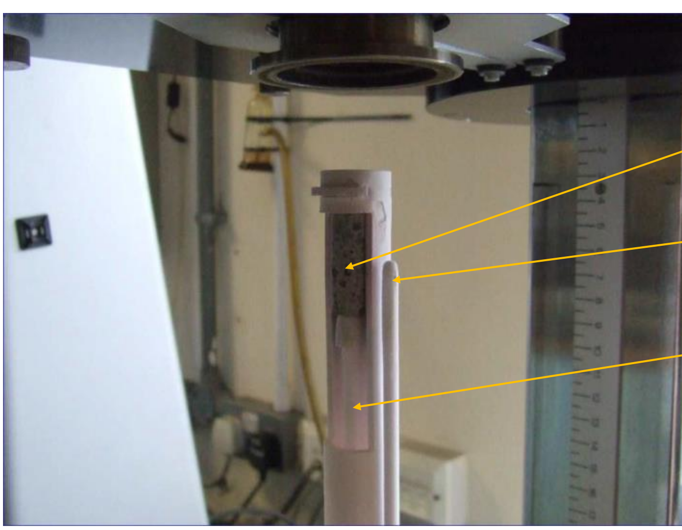
Vertical Dilatometer

Maximum Operating Temp = 1600℃

Tests can be run in air or controlled atmosphere (nitrogen or argon)

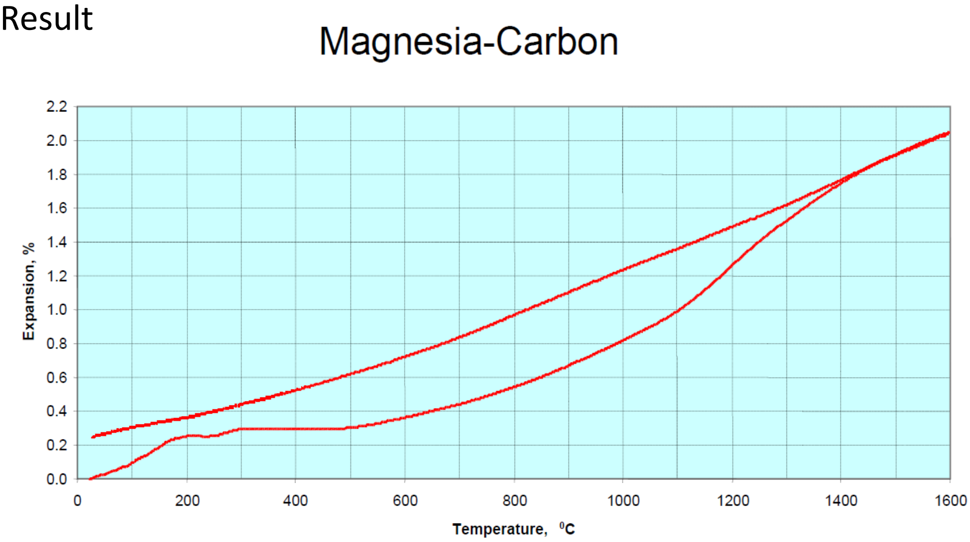
A highly sensitive linear velocity displacement transducer (LVDT) accurately measures expansion / shrinkage

Thermal Expansion



Thermal Expansion

Typical Result



Monolithics

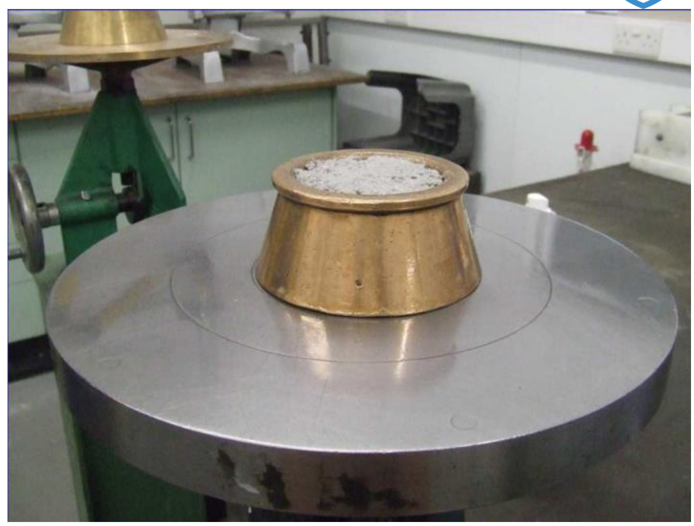
Flowability of Dense Castables

Principle :

- A standard size test specimen is prepared from freshly mixed material and placed on a flow table conforming to BS890 or ASTM C230.
- The specimen is then deformed by raising and dropping the table top through a known height a prescribed number of times.
- The diameter of the test sample is then measured at two points at right angles to each other and the mean diameter is recorded as the flow value.

Flowability of Dense Castables

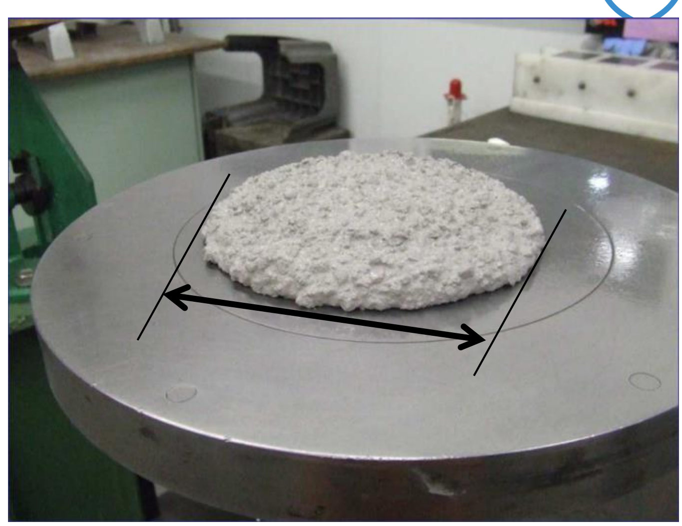
- Mould filled just over half way and vigorously tamped to form a fully compacted homogeneous layer.
- Remainder of mould filled and tamped in identical manner
- Mould is then carefully removed and the flow table top is the raised and dropped fifteen times in a minimum of fifteen seconds.



Flowability of Dense Castables

After raising and dropping the table top fifteen times, the diameter of the test sample is measured in two positions at right angles using vernier calipers

For Self-Flow Castables, the table is not raised and dropped. The flow is measured after 1 minute



Setting of Castables

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Principle :

A sample of castable is mixed with a standard water addition and placed in a plastic bag.

The bag contents are vibrated to compact the material and the bag is then left undisturbed in a constant temperature environment.

The sample is tested with the Ridsdale Green Hardness tester, scale C, periodically and the time noted when a reading of 80 or above is obtained at two or more points on the surface of the sample.

Having recorded the time the test commenced, the setting time is recorded as the time elapsed between these two points.

Setting of Castables

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Hardness of castable monitored over time using Ridsdale hardness tester

Particle Sizing

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Standard Screen Sizes

- 8 mm
- 4 mm
- 2.8 mm
- 2.0 mm
- 1.0 mm
- 0.5 mm
- 0.25 mm
- 125 μm
- 63 μm

Particle Sizing – Laser Sizer

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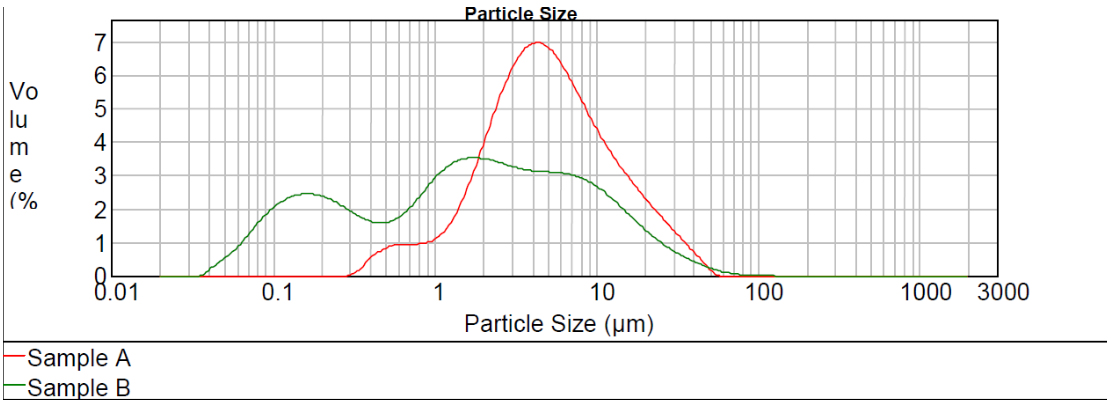
Principle :

Laser diffraction measures particle size distributions by measuring the angular variation in intensity of light scattered as a laser beam passes through a dispersed particulate sample.

Particle Sizing – Laser Sizer



Summary

Standard physical tests provide

– The base knowledge for consistency

– Limited characterisation of the material

Cannot predict how well a product will perform in service

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Thank You

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