Institute of Refractories Engineers

Properties of Refractories

Sheffield

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Prepared by K.Booth / K.Beale

Presented by Andy Brewster

Physical Testing - Why

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

Physical Testing

- 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	BSEN 993-1
CCS	ISO10059-2
Cold MOR	BSEN 993-6
Hot MOR	BSEN 993-7
Particle Size Analysis	In-House Method
Flow Properties / Setting Time	In-House Method
PLC	BSEN 993-10
Thermal Expansion	In-House Method

Routine Refractory Testing

BSEN 993-1 Determination of bulk density and apparent porosity

Definitions :

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

Routine Refractory Testing

BSEN 993-1 Determination of bulk density and apparent porosity

Apparatus :

Evacuating Equipment

Balance

Routine Refractory Testing

BSEN 993-1 Determination of bulk density and apparent porosity

Samples Under Water Prior to Weighing

Routine Refractory Testing

BSEN 993-1 Determination of bulk density and apparent porosity

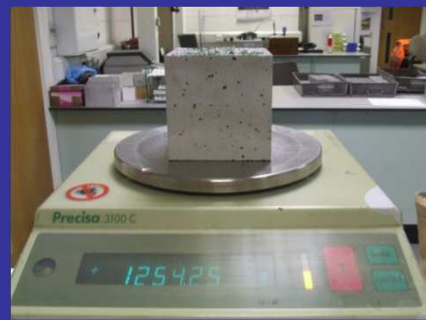
Measurements :

m_1 = mass of dry test piece

m_2 = apparent mass of immersed test piece

m_3 = mass of soaked test piece

p_{liq} = Density of immersion liquid



Routine Refractory Testing

BSEN 993-1 Determination of bulk density and apparent porosity

Calculations :

Bulk Density = $\dfrac{m_1}{m_3 - m_2} \times p_{liq}$

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

m_1 = mass of dry test piece

m_2 = apparent mass of immersed test piece

m_3 = mass of soaked test piece

p_{liq} = Density of immersion liquid

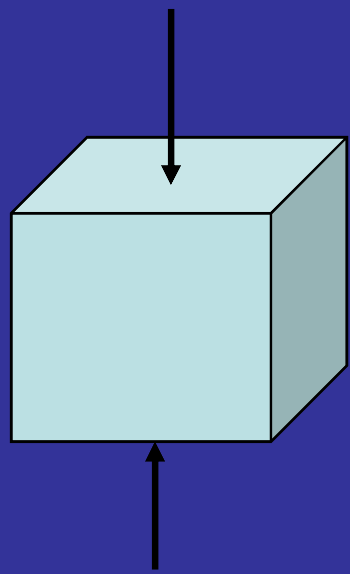
Routine Refractory Testing

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



Routine Refractory Testing

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%

Routine Refractory Testing

Cold Compression Testing

Sample Loading

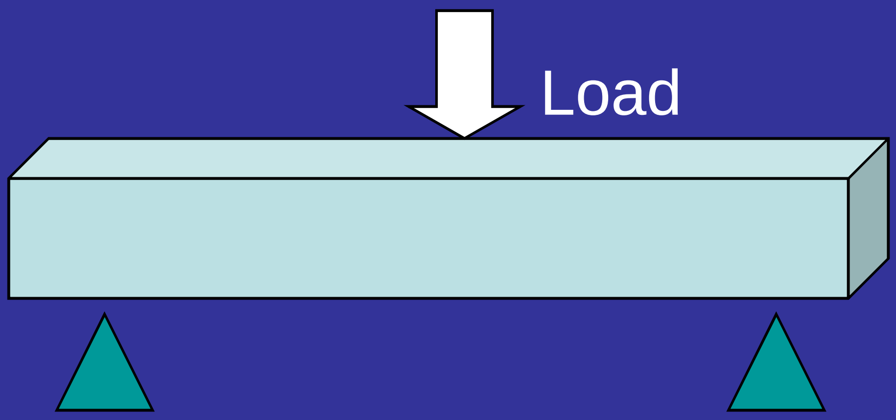
Failed Sample

Routine Refractory Testing

BSEN 993-6 / BSEN 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.



Routine Refractory Testing

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 :

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

Maximum load (Failure Load) in flexure is actually recorded

Flexural Stress is calculated from load and test piece dimensions

Units N/mm^2 (MPa)

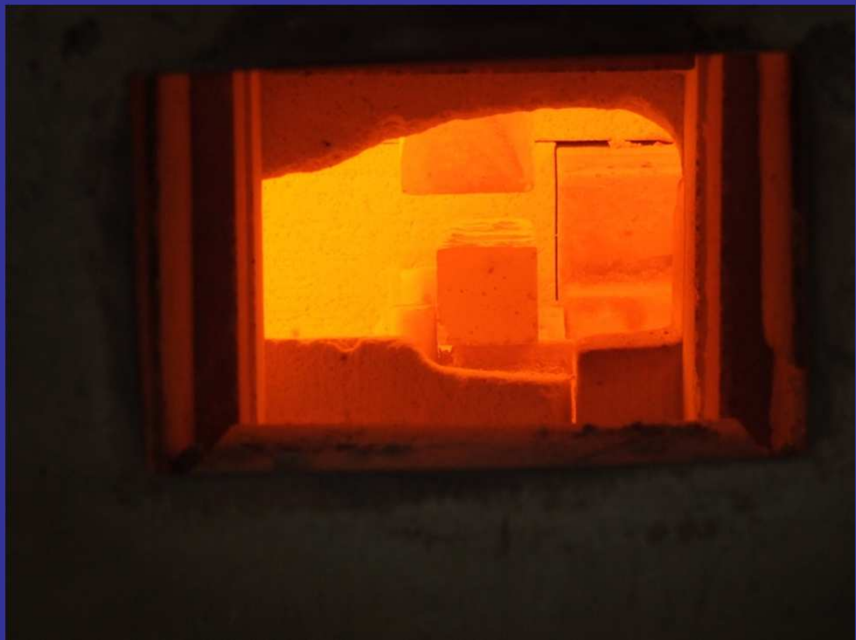
Can be measured at ambient or elevated temperatures.

Routine Refractory Testing

Cold MOR / Hot MOR

Routine Refractory Testing

Cold MOR / Hot MOR



Routine Refractory Testing

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 then cooled to ambient temperature.

Routine Refractory Testing

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

Equipment :

Furnace

Vernier Calipers (Method 2)

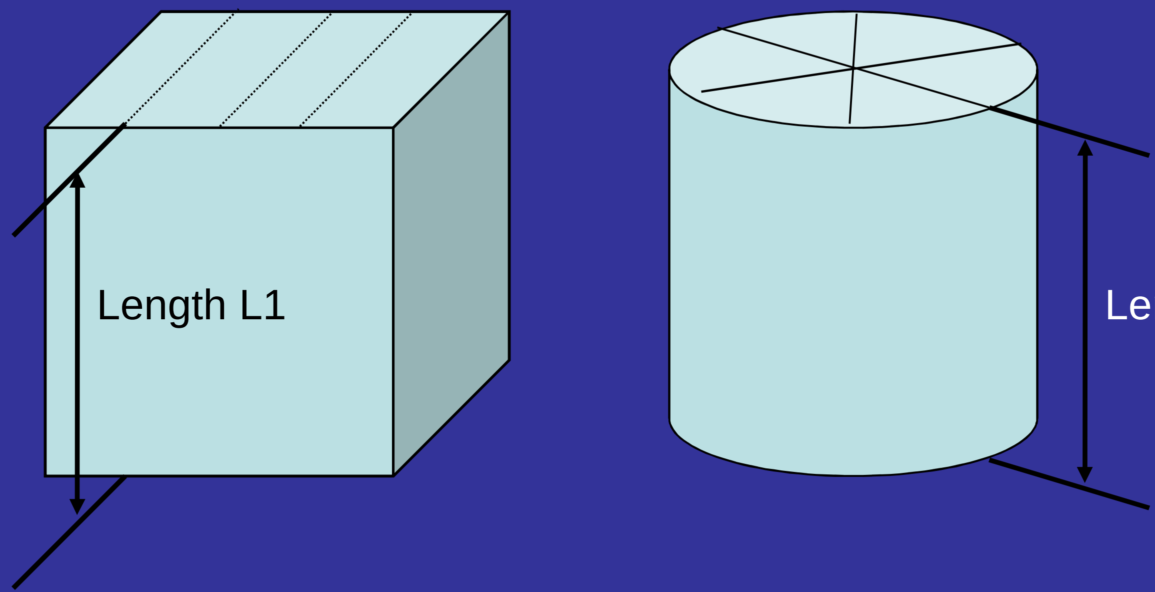
Test Pieces :

Rectangular Prism 50 x 50 x 60mm

Cylinders 50mm diameter x 60mm height

Routine Refractory Testing

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



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

Routine Refractory Testing

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

Heating Rates

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

Routine Refractory Testing

Thermal Expansion

The proportional extension which occurs when a material is heated. BS1902 Pt 5.

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

Routine Refractory Testing

Thermal Expansion

Linseis Vertical Dilatometer

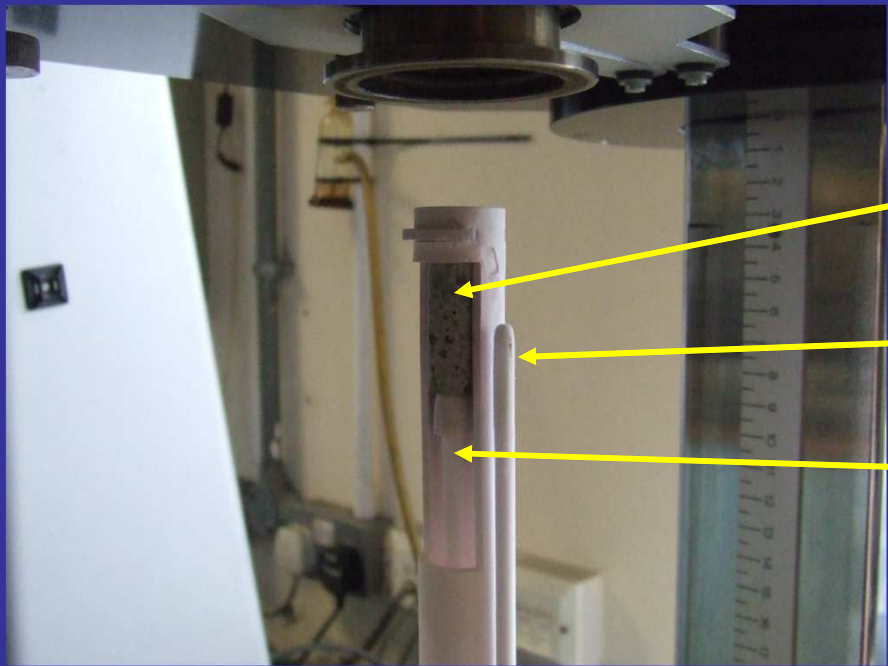
Maximum Operating Temp = 1600^{0}C

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

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

Routine Refractory Testing

Thermal Expansion



Test Sample

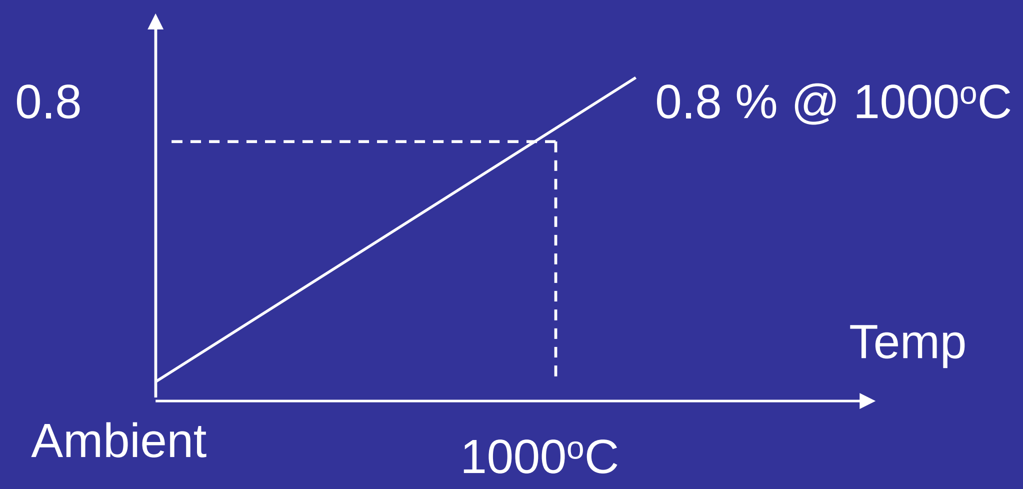
Thermocouple

Alumina Measuring Rod

Routine Refractory Testing

Thermal Expansion

Results can be plotted graphically.

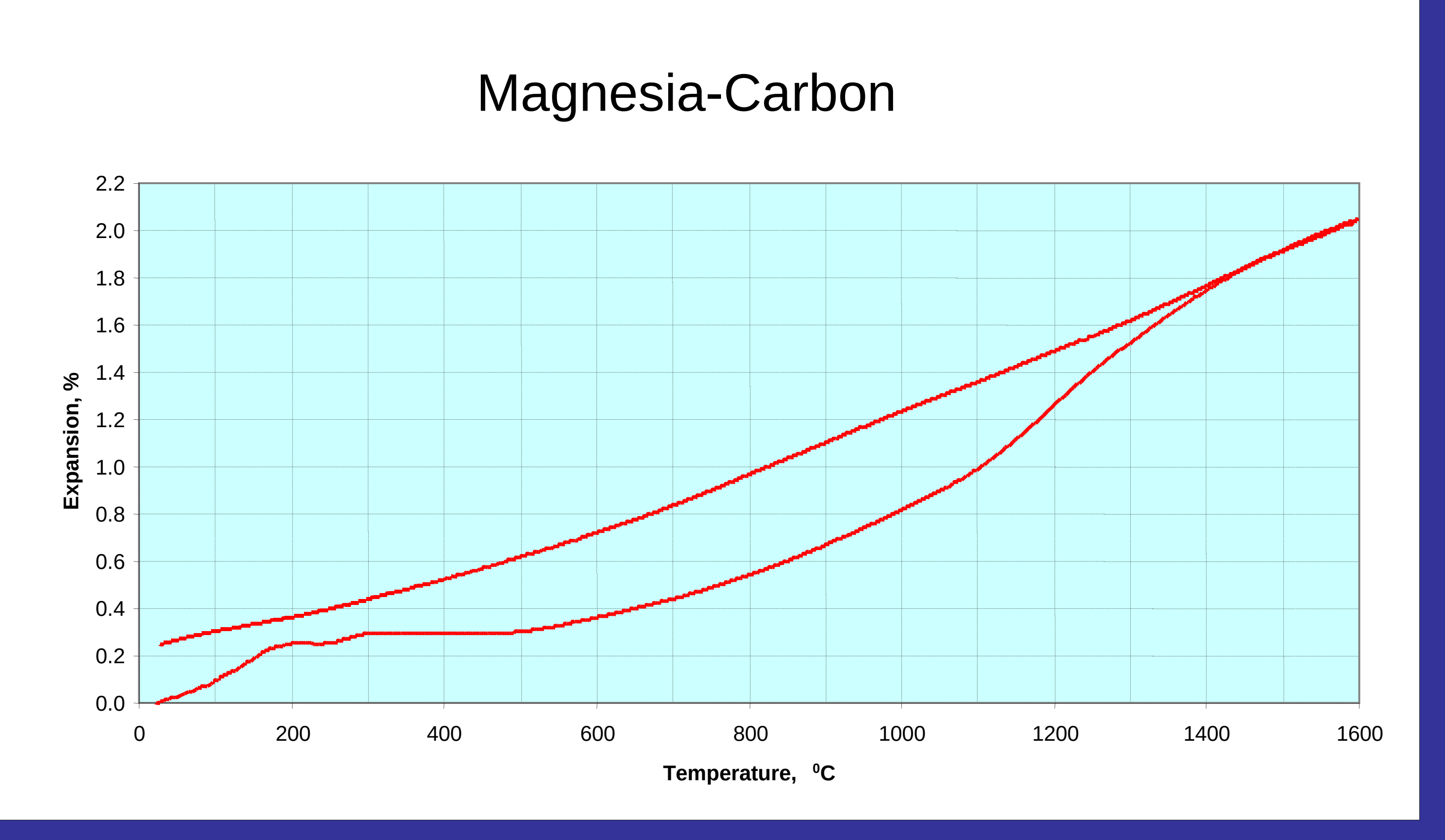


Or quoted as a mean co-efficient of expansion per unit of temperature up to a specified maximum temperature.

The co-efficient of thermal expansion up to 1000^{o}C would be 0.0008 i.e. it would expand 0.0008% for every ^{o}C temperature increase.

Routine Refractory Testing

Typical Thermal Expansion



Routine Refractory Testing

Monolitihcs 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.

Routine Refractory Testing

Monolitihcs Flowability of Dense Castables

Flow Table With Bronze Mould

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.

Routine Refractory Testing

Monolitihcs Flowability of Dense Castables

Flow Table With Bronze Mould

Bronze mould is then carefully removed and the flow table top is the raised and dropped fifteen times in a minimum of fifteen seconds.

Routine Refractory Testing

Monolitihcs   Flowability of Dense Castables

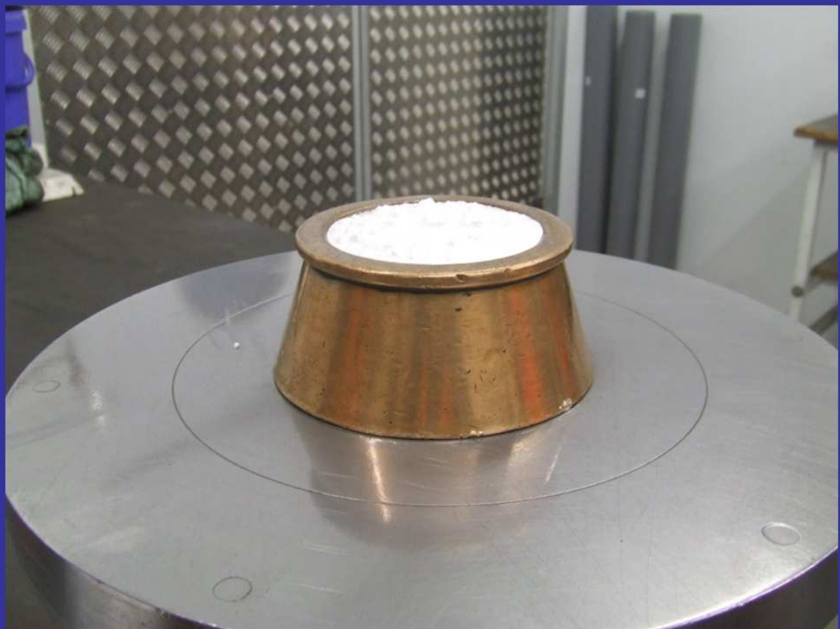
Flow Table With Bronze Mould

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

Routine Refractory Testing

Monolitihcs Flowability of Self-Flow Castables

Flow Table With Bronze Mould

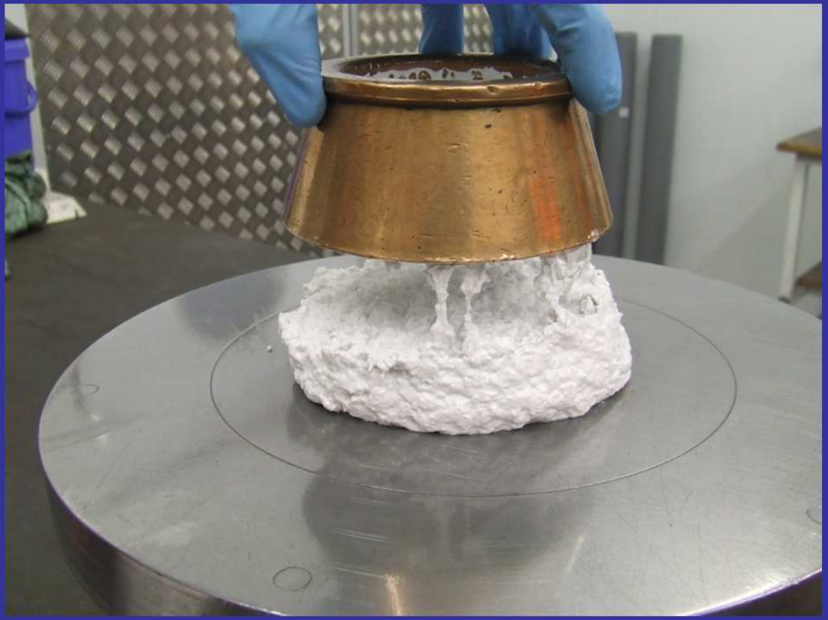


Mould filled is filled to top with self-flow castable

Routine Refractory Testing

Monolitihcs   Flowability of Dense Castables

Flow Table With Bronze Mould



Bronze mould is then carefully removed and the test sample is allow to flow for one minute.

Routine Refractory Testing

Monolitihcs Flowability of Dense Castables

Flow Table With Bronze Mould

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

Routine Refractory Testing

Monolitihcs   Setting of Castables

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.

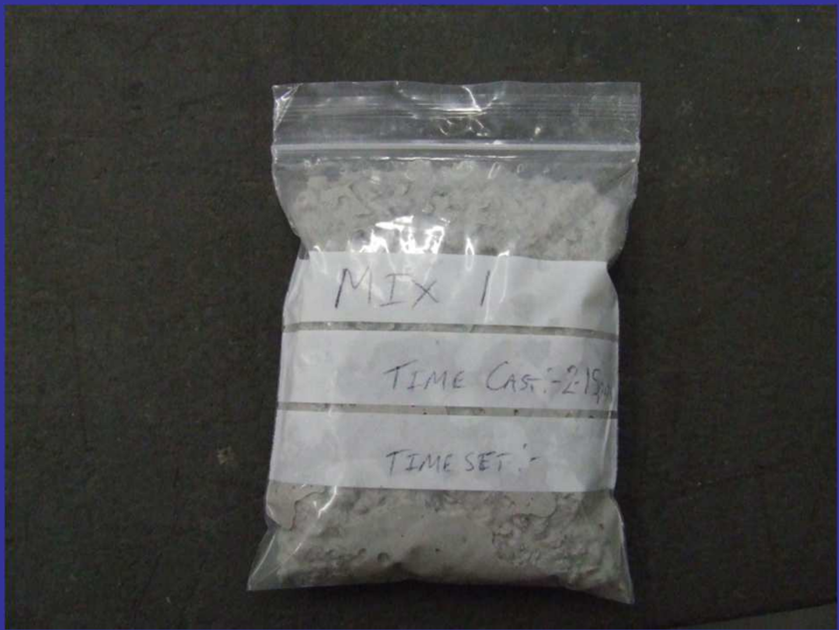
The sample is tested with the Ridsdale Green Hardness tester, scale C, periodically and the time noted when a reading of 80 or above is obtained at two or more points on the surface of the sample.

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

Routine Refractory Testing

Monolitihcs   Setting of Castables

Consolidated castble in bag with time recorded. Hardeness of castable monitored over time using Ridsdale hardness tester



Routine Refractory Testing

Monolitihcs   Setting of Castables

Hardness Reading = 55

Hardness Reading = 80

Routine Refractory Testing

Particle Sizing

Standard Screen Sizes

8 mm
4 mm
2.8 mm
2.0 mm
1.0 mm
0.5 mm
0.25 mm
125 microns
63 microns

Routine Refractory Testing

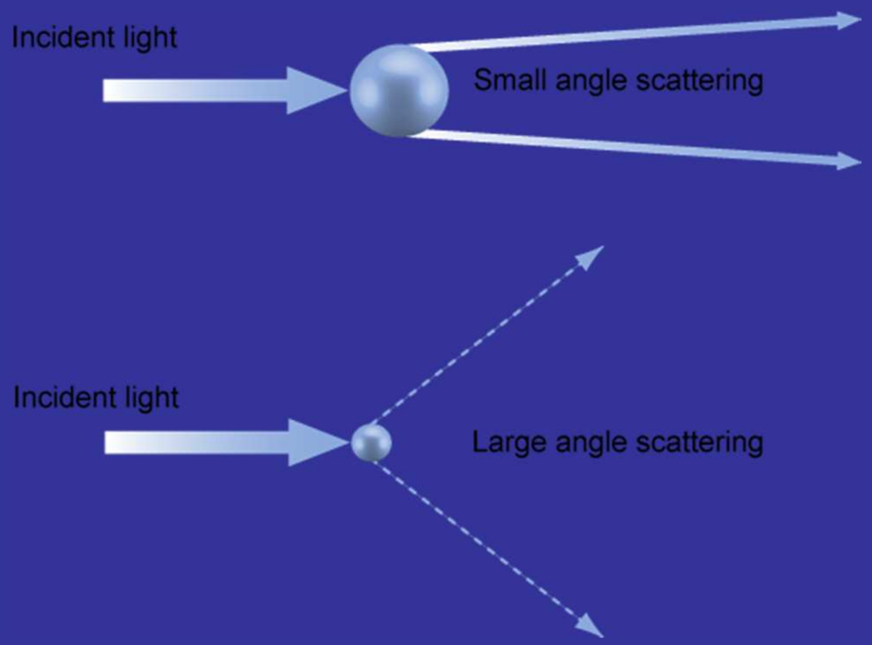
Particle Size Analysis – Laser Sizer

Routine Refractory Testing

Particle Size Analysis

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.



Large particles scatter light at small angles relative to the laser beam and small particles scatter light at large angles, as illustrated.

The angular scattering intensity data is then analyzed to calculate the size of the particles responsible for creating the scattering pattern, using the Mie theory of light scattering.

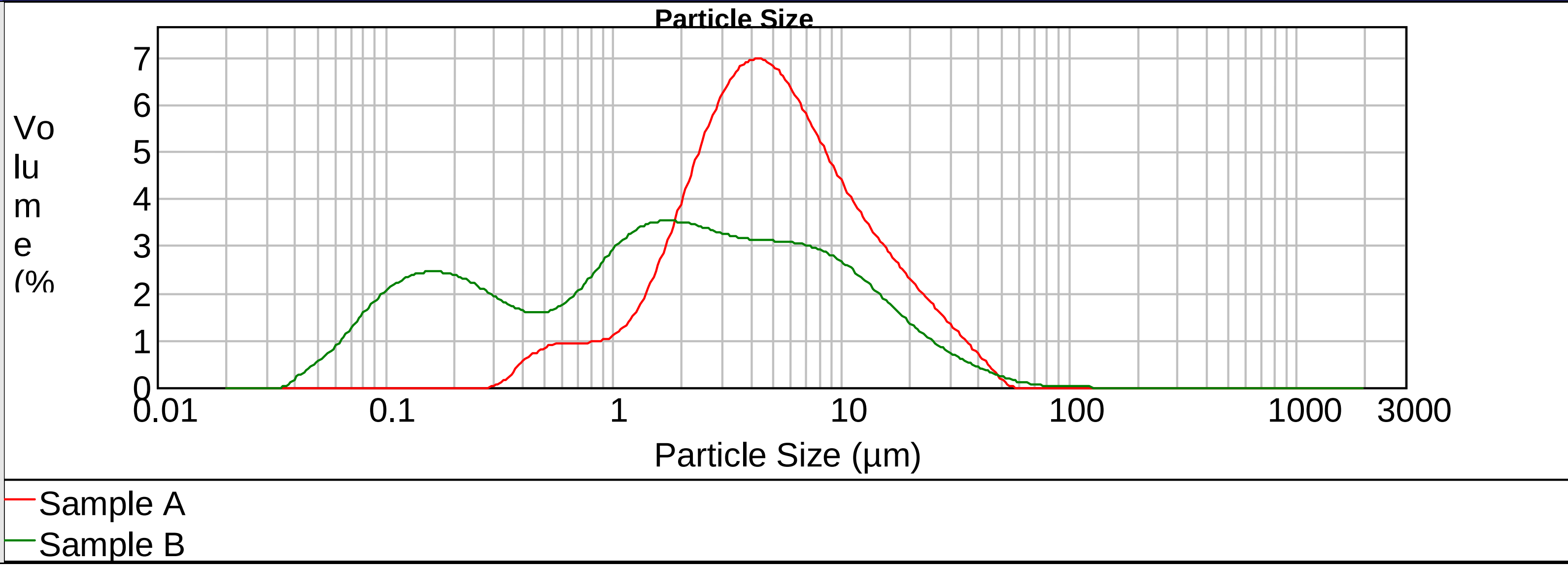
The particle size is reported as a volume equivalent sphere diameter.

Routine Refractory Testing

Particle Size Analysis

MALVERN MASTERSIZER - PARTICLE SIZE ANALYSIS

SAMPLE: **Samples A and B**



	Sample A	Sample B
D_{50}, µm	4.815	1.754
Specific Surface Area, m^2/g	1.977	3.800

Physical Testing - 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