R&D
Carbon

RAMMING PASTE EVALUATION

PREPARATION AND TEST METHODS

Auteur : **JW**

Version: **4**

Date : **18.12.2013**

Table of contents

1 Ramming Paste Preparation

The ramming paste is compacted using a pneumatic hammer in layers of about 4 cm till a 45 l steel case is filled. The paste is also pressed using a pilot press with a 146 mm diameter. The comparison between the mechanical properties of the rammed block and the pressed electrodes allows a better understanding of the problems relating to a non satisfactory paste.

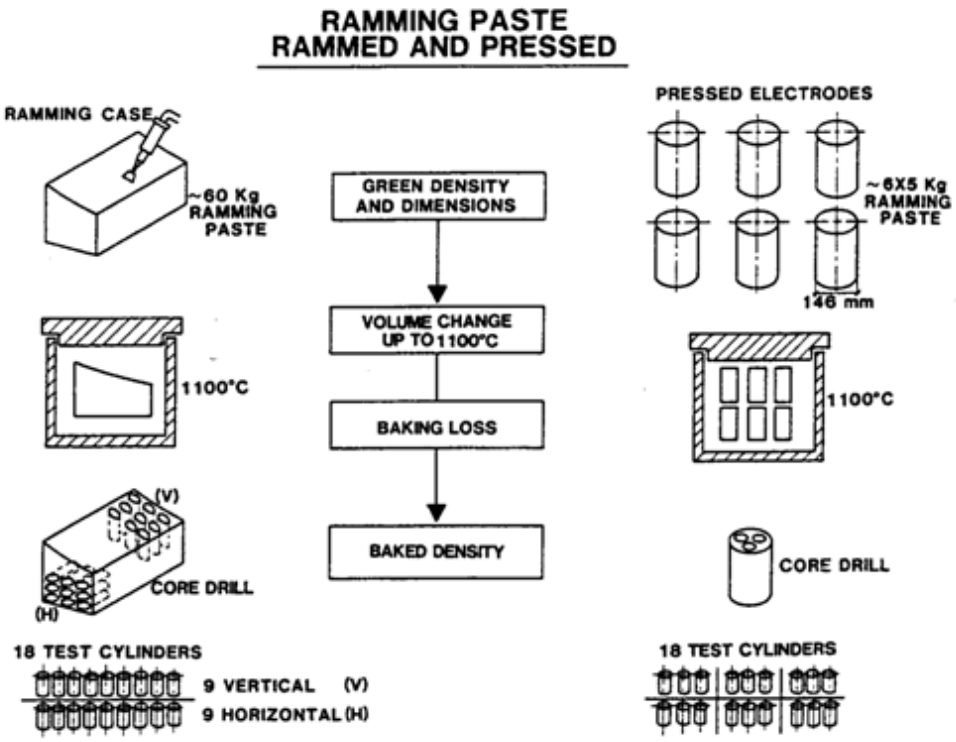
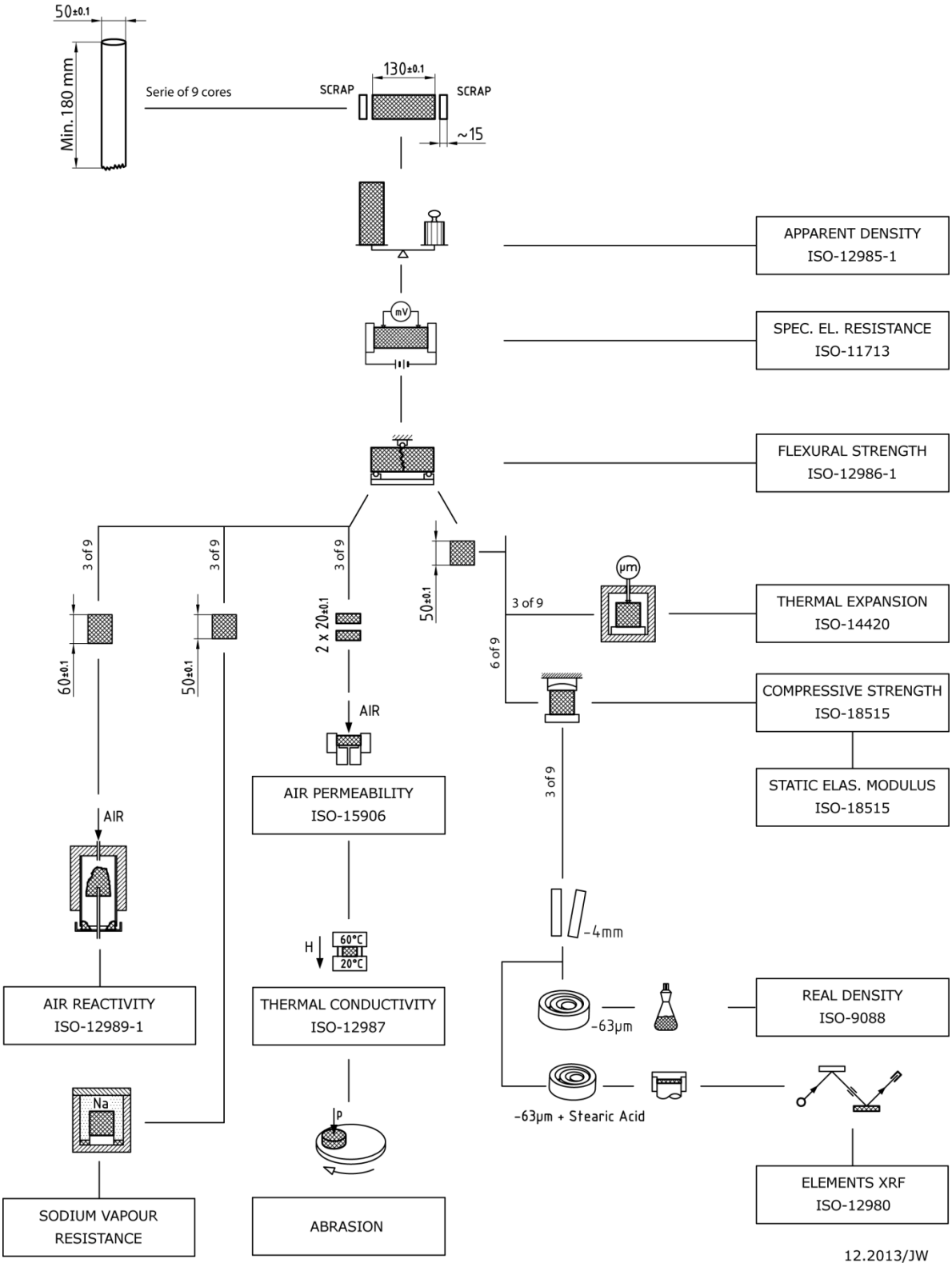


Figure 1: Ramming paste preparation

The pressed electrodes as well as the rammed block are baked up to 1100°C. After baking, 18 cores are drilled from the rammed block (9 per direction) and 18 cores are drilled for the pressed pilot.

The test schedule on the next page shows the analysis which are made on a set of 9 cores.

TEST SCHEDULE
RAMMING PASTE



2 Test Methods

The paste is rammed at the recommended manufacturer's temperature, nevertheless the knowledge and control of the temperature window where the paste can be rammed appropriately is necessary. This is the first test done on the paste using an automatic Sand Rammer.

2.1 Temperature Window: ISO 17544

This test was developed by Solie and Oye, and presented during AIME 87. The compaction takes place as the energy from a falling weight is transferred to 180 g of paste formed in a 50 mm cylinder. The length of the paste can be read directly to the nearest 0.01 mm and the density increase up to 350 strokes. The temperature window is determined by running at 3 different temperature levels (usually at the recommended temperature and 15°C below and above).

The density d_R of the ramming cylinders can be described by an exponential function:

$$d_R = d_{max} - \Delta d \cdot e^{\frac{-N}{N_0}}$$

where

d_{max}	=	maximum density after 350 strokes
Δd	=	difference between d_{max} and the density after stroke (d_0)
N	=	Number of strokes
N_0	=	Stroke parameter

According to Sorlie and Oye the temperature window is then determined by plotting N_0 versus the temperature and estimating the temperature range where N_o lies between 25 to 40 strokes.

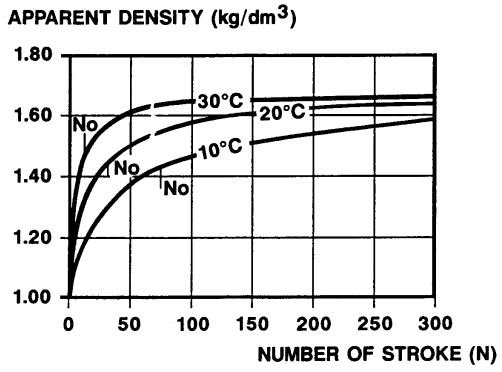


Figure 2: Compaction curves of a ramming paste at three different temperatures

2.2 Paste Shrinkage: ISO 14428

The shrinkage of the paste during baking is measured using 100 strokes paste formed specimen at the recommended manufacturer's temperature (or depending on the pre-determined optimal temperature) according to ISO 14427.

From a non-plastic temperature range (starting from 400°C) shrinkage occurs. From 0.3% of linear shrinkage the risk of cracks during paste baking is non-negligible.

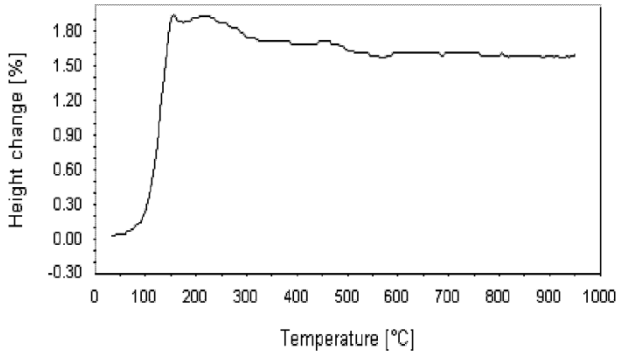


Figure 3: Typical ramming paste dilatation curve

2.3 Baked Apparent Density: ISO 12985-1

The baked apparent density (BAD) is determined by weighing a dried 130 mm long core sample. The apparent density results are given in kg/dm^3. The ADB itself is not a relevant property but it allows the calculation of the total porosity in combination with the real density in xylene. For a given raw material, low porosity means a good compaction.

2.4 Real Density in Xylene: ISO 9088

The real density in xylene (RDX) is measured in a pycnometer with xylene on a sample ground to <63 µm grain size.

The real density in xylene of the baked ramming paste depends mainly on the xylene density of the dry aggregate.

2.5 Total Porosity

The total porosity is calculated from the real density in xylene (RDX) and the baked apparent density (BAD) according to the equation below:

$$TP\ [\%] = \frac{RDX - BAD}{RDX} \cdot 100$$

2.6 Air Permeability: ISO 15906

The air permeability is determined by measuring the time taken for a certain volume of air to pass through a sample of 50 mm diameter and a length of 20 mm. The results are expressed in nano perms (nPm).

Figure 4: RDC 145 Air permeability apparatus

2.7 Thermal Conductivity: ISO 12987

The thermal conductivity is determined by a comparative method using a sample with a diameter of 50 mm and a length of 20 mm. The surfaces of the sample are very smooth due to the use of a special grinding machine with two blades.

The heat flow is measured between electrically heated (60°C) and water-cooled (20°C) metallic measuring heads. The results are expressed in W/mK.

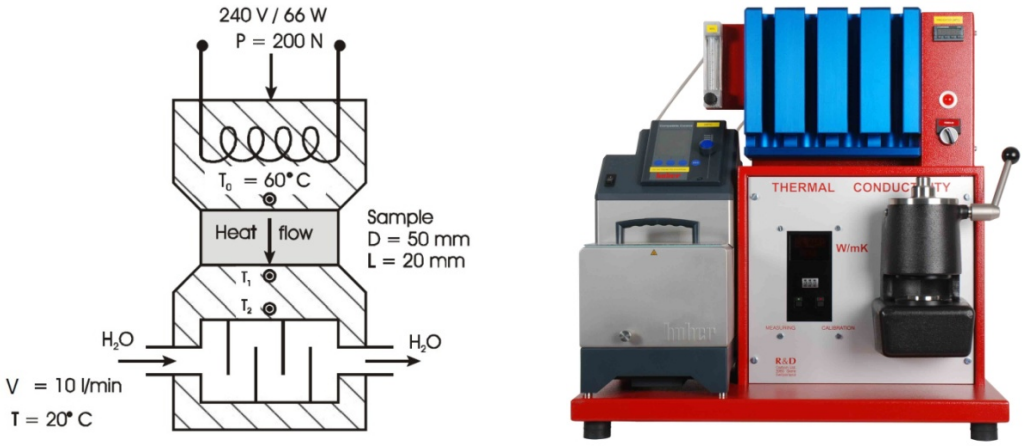


Figure 5: Test arrangement for the determination of the thermal conductivity

The conductivity is mainly influenced by the nature of the dry aggregate and by the porosity level. The thermal conductivity of the ramming paste has some importance for ledge formation.

2.8 Specific Electrical Resistance: ISO 11713

The specific electrical resistance (SER) is determined by measuring the voltage drop on a 50 mm diameter by 130 mm length sample at a constant current of 1 ampere. The test arrangement is shown below. The results are expressed in µΩm.

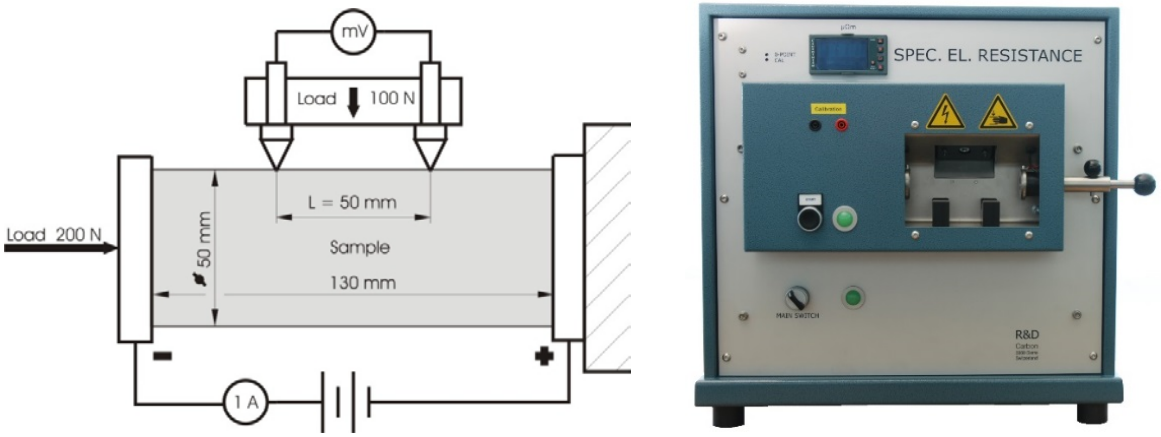


Figure 6: Test arrangement for the determination of the specific electrical resistance

A strong variation of the SER indicates the presence of cracks due to the poor compactability of the paste.

2.9 Flexural Strength: ISO 12986-1

The flexural strength (FS) is determined using the three points loading on a sample with 50 mm diameter and 130 mm length. The test arrangement is shown in the figure below. The values are reported in MPa.

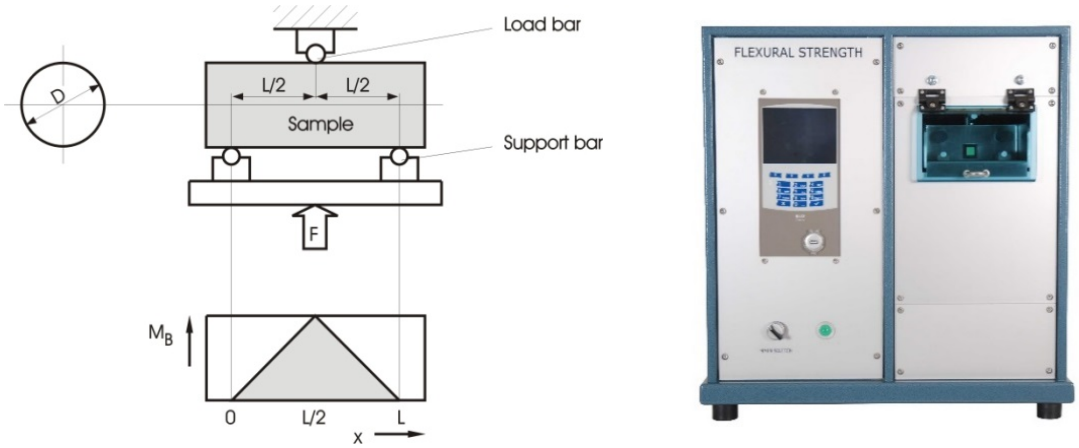


Figure 7: Test arrangement for the determination of the flexural strength

The flexural strength is influenced by the amount of binder and the recipe line, but also by the compactability of the paste. A lack of adherence between the layers of ramming paste will directly result in a low flexural strength level.

2.10 Compressive Strength and Young's Modulus: ISO 18515

Compressive strength (CS) and Young's Modulus (SEM) are determined from the breaking load on the linear compression of a sample with 50 mm diameter and 50 mm length. Normally the compressive strength shows values four times higher than the flexural strength. The test arrangement is shown in the figure below. The values are reported in MPa for the compressive strength and in GPa for the Young's modulus (also called static elasticity modulus).

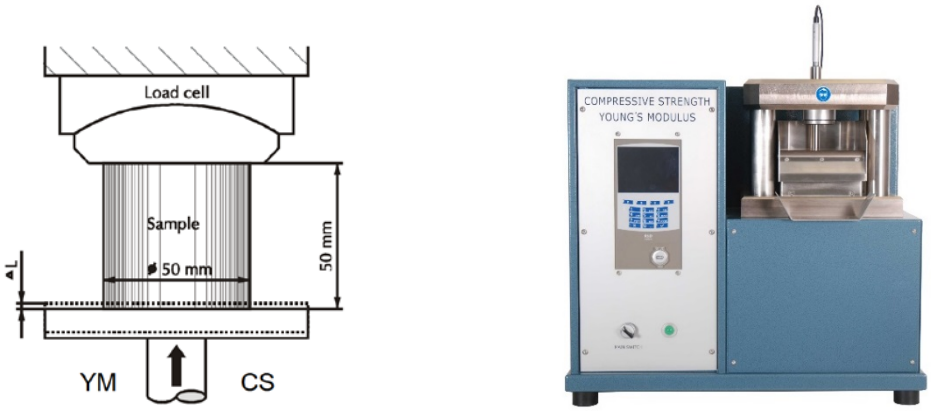


Figure 8: Test arrangement for the determination of the compressive strength and Young's modulus

The compressive strength and Young's modulus are important parameters considering the thermal shock resistance. The CS is a property to be considered especially if the level is too low (<10 MPa).

2.11 Coefficient of Thermal Expansion: ISO 14420

The coefficient of thermal expansion is measured between 25°C and 300°C and reported as a mean coefficient in 10^{-6} K^{-1}.

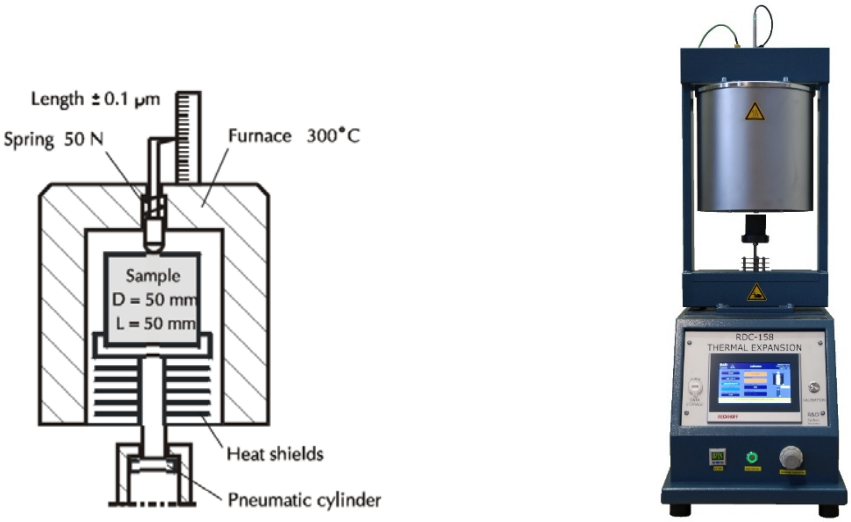


Figure 9: Test arrangement for the determination of the coeff. of thermal expansion

2.12 Air Reactivity: ISO 12989-1

The air reactivity is tested by preheating a 50 mm diameter and 60 mm length sample at 550°C in an inert atmosphere and then by cooling it with a gradient of 15°C/h to 400°C in an air flow of 200 l/h. In order to collect the dust in a cold area, the sample is cyclically tapped. The test arrangement is shown in the figure below.

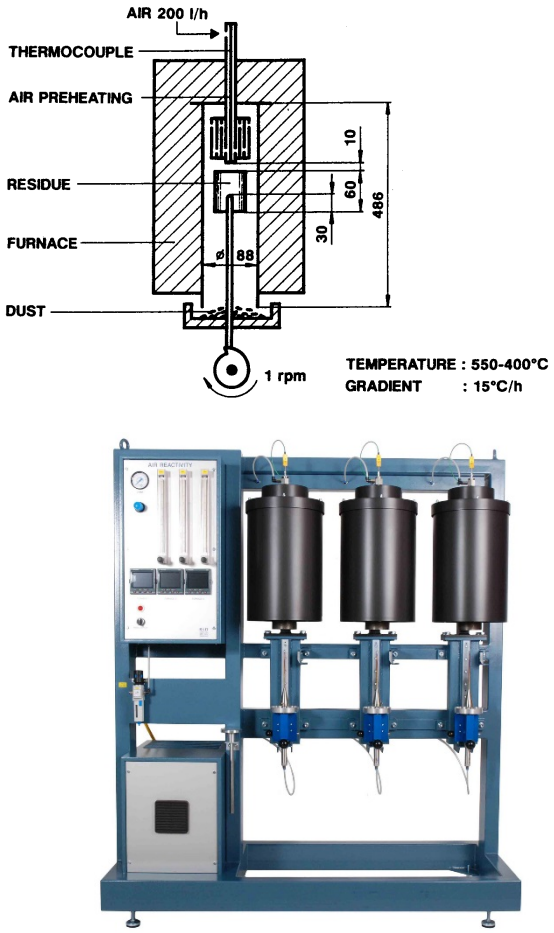


Figure 10: Test arrangement for the determination of the air reactivity

After the test, the sample is put together with steel balls for 20 minutes in a tumbling apparatus in order to measure the removed dust. The results are reported in percent as follows:

- Air reactivity residue (ARR): residual sample
- Air reactivity loss (ARL): loss due to air burn
- Air reactivity dust (ARD): removed grains

The air reactivity is an important property as baked ramming paste burning is possible. The air reactivity is primarily affected by the reactivity of the filler and by the quantity of the binder.

2.13 Abrasion: M191

Abrasion of the ramming paste is due to the abrasive alumina sludge driven by the metal movements.

A test where the baked ramming paste cores of 50 mm diameter and a length of 20 mm is ground under a load of 200N on a 60 SiC wheel was developed. The height of the sample after the test is measured and the loss in height is reported in percent.

Figure 11: RDC 191 Abrasion apparatus

2.14 Sodium Vapour Resistance: M192

A specimen of 50 mm diameter and 50 mm length is introduced in a stainless steel vessel together with an equivalent weight of sodium. After evacuation to 100 mbar, the temperature is increased to 800°C, causing the pressure to increase from 100 to 500 mbar. Samples are kept out after 4 hours at 800°C. The test arrangement is shown in the figure below.

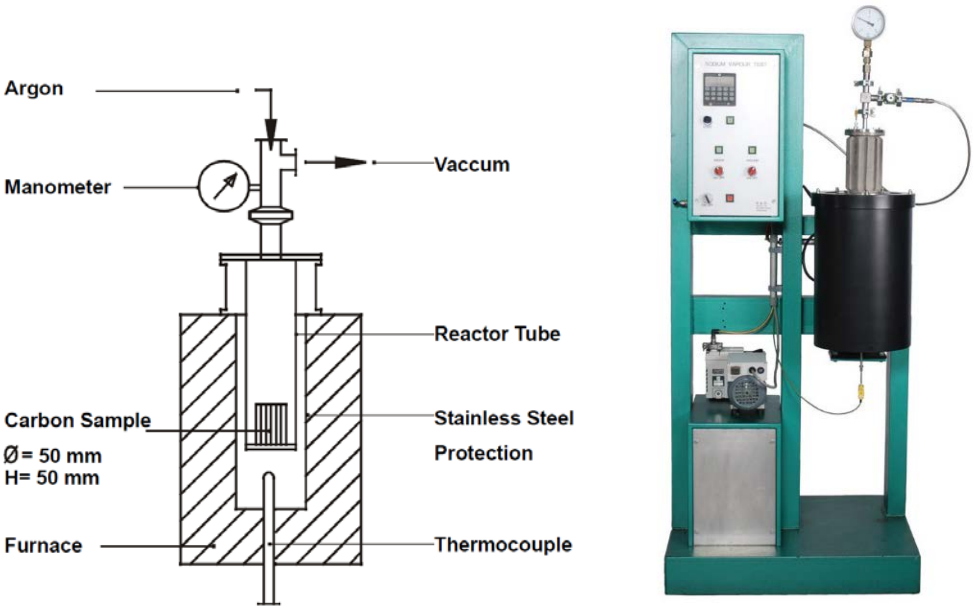


Figure 12: Test arrangement for the determination of the Na vapour resistance

The effect of sodium attack is quantitatively determined by comparing the compressive strength values measured on the cores after the test to the values obtained on the original material. The sodium vapour resistance is defined as the ratio in percent of the strength after the test to the original strength.

Graphitic ramming paste shows better resistance towards sodium than pure amorphous paste. A compromise between this chemical and mechanical (abrasion) resistance gives the best results (long pot life) in practice.

2.15 Elements XRF: ISO 12980

The contaminants are determined by the use of an X-Ray spectrometer. While not a relevant characteristic, the change in the impurities level gives an indication of inconsistent raw materials quality.

Figure 13: EXT 103 XRF Spectrometer

3 Typical Values

The data are presented in sheets where the rammed and the pressed core properties can be compared to each other and to typical ranges for ramming paste available on the market. The tables below summarize the typical ranges for ramming paste.

Properties	Unit	Typical Range		
		Cold	Tepid	Warm
Temperature Window	°C	15-35	35-50	75-90
Paste Shrinkage	%	0.0-0.3	0.1-0.3	0.1-0.3

Table 1: Summary of typical ranges for cold, tepid and warm ramming paste

Property		Unit	Typical Range		
			Pressed	Rammed	
				Vertical	Horizontal
Green Apparent Density		kg/dm^3	1.55-1.70	-	
Baking Loss		%	6-9	-	
Volumetric Expansion		%	1-3	-	
Baked Apparent Density		kg/dm^3	1.40-1.54	1.42-1.56	
Total Porosity		%	18-24	20-28	
Specific Electrical Resistance		µΩm	54-80	54-80	50-70
Thermal Conductivity		W/mK	2-7	2-7	2-9
Flexural Strength		MPa	4-7	2-6	3-9
Compressive Strength		MPa	15-40	10-35	15-45
Static Elasticity Modulus		GPa	1.5-4.0	1.0-3.5	1.5-4.5
Thermal Expansion		$10^{-6}K^{-1}$	3-4	3-4	2-3
Air Permeability		nPm	1-10	3-30	
Real Density in Xylene		kg/dm^3	1.70-1.94	1.70-1.94	
Air Reactivity	Residue	%	60-90	50-90	
	Dust	%	5-30	5-40	
	Loss	%	5-10	5-10	
Abrasion		%	1-3	1-3	
Na Vapour Resistance		%	40-90	40-80	
Elements XRF	S	%	0.3-0.6	0.3-0.6	
	Si	%	0-2	0-2	
	Fe	%	0.1-0.6	0.1-0.6	
	Al	%	0-2	0-2	
	Na	%	0.01-0.05	0.01-0.05	
	Ca	%	0.01-0.20	0.01-0.20	

Table 2: Typical values for ramming paste