Monolithic linings of cement kilns under conditions of combustion of alternative fuels

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Annotation

The increasing share of alternative fuels burned in cement kilns significantly influences the built-in refractory linings. The presented contribution deals with changes of operating conditions with regard to their impact on the refractory linings. It describes specific situations in individual parts of cement kiln plants. It specifies frequent failures of refractory linings, in our case primarily of monolithic ones, and names their causes. It suggests solutions that could eliminate these failures and secure a longer lifetime of the linings. Besides, it mentions practical long-standing results and experiences of lining installations in many, mainly Slovak cement factories.

1. Introduction

The refractory lining of cement kiln lines is one of their most important parts because only its reliable operating condition allows you to continuously operate this sophisticated plant. Almost every failure of the lining results in immediate shut-down of the whole plant. The massive expansion of combustion of so-called alternative fuels in the last more than 10 years has big impact on the lifetime of installed refractories and the whole lining constructions made from them. The authors of the contribution and their companies (a manufacturer of non-shaped refractories and a firm installing refractory linings) went through all of these operating changes in this demanding period. Almost on the hoof, they had to deal with the development and applications of completely new refractories, and design new lining arrangements, their stabile attachment and installations often in extreme climatic conditions. This occurred on processing equipment, whose shut-down always brings huge economic losses. The presented contribution describes the actual condition in the selection of refractory monoliths for cement kiln lines and structural design of linings under conditions of combustion of the maximum possible quantity of alternative fuels.

2. Alternative fuels for cement kilns

The best solution for the company is to increase the value of wastes in the material way. If it is not possible, then their energetic use is suitable. The cement industry offers an environmentally suitable method of dangerous waste disposal. The energy use of wastes in cement kilns saves irreplaceable fossil fuels, reduces emissions and eliminates the need to stock-pile the clinker and ash.

The cement line of a rotary kiln is an ideal unit to dispose of chemically dangerous materials. The disposal runs through chemical bonding to the cement raw material and decomposing under high temperatures. Another important factor is the reduction of CO_2 emissions up to 50%. Chemical substances bind not only to limestone but they react also to the refractory under certain temperatures, which adversely affects its lifetime. The mentioned reaction occurs depending on the position where alternative fuels are dosed into the kiln system [1].

The dosing usually runs through the main burner but as alternative fuels are used in more and more kinds, they can be dosed into the line also through the footing piece or through the calciner or they are combusted in the so-called Hot Disc unit. Therefore the temperature fields move in the kiln system and the positions change where dangerous materials can react to the lining, which results in degradation of refractories. To prevent from the mentioned undesirable condition and lengthen the lining lifetime at least to one (annual) campaign, we must install a refractory into places that will be resistant to the operating temperature and mechanical and chemical wear.

The assortment of alternative fuels includes a wide range of mainly solid but also liquid substances. The most important are tires, plastics (PE, PVC and many others), textile, bone meal, saw-dust saturated with oil and similar compounds, low-quality coal. As for liquid substances we can name refinery wastes, used mineral oils etc. Generally speaking, the linings are not damaged by the organic matters but primarily by inorganic compounds present in them or originating from them in the kiln environment. They are mainly potash and sodium salts, such as sulphates and sulphites, chlorides, fluorides etc. [2, 3].

3. Impact of fuels on individual lining parts

A cement kiln is a very sophisticated facility and the impact of alternative fuels, in better words, products of their thermic decomposition, is very different in various parts of this plant. Therefore we divided a cement kiln line into several parts in our contribution and we analyze both operating conditions and experiences and recommendations of a suitable refractory. See Fig.1. With regard to orientation of the company Průmyslová keramika to the production of non-shaped refractories, the contribution is primarily oriented to those places of the cement kiln line where these materials are usually installed. Basically, it can include the whole kiln line except the rotary kiln.

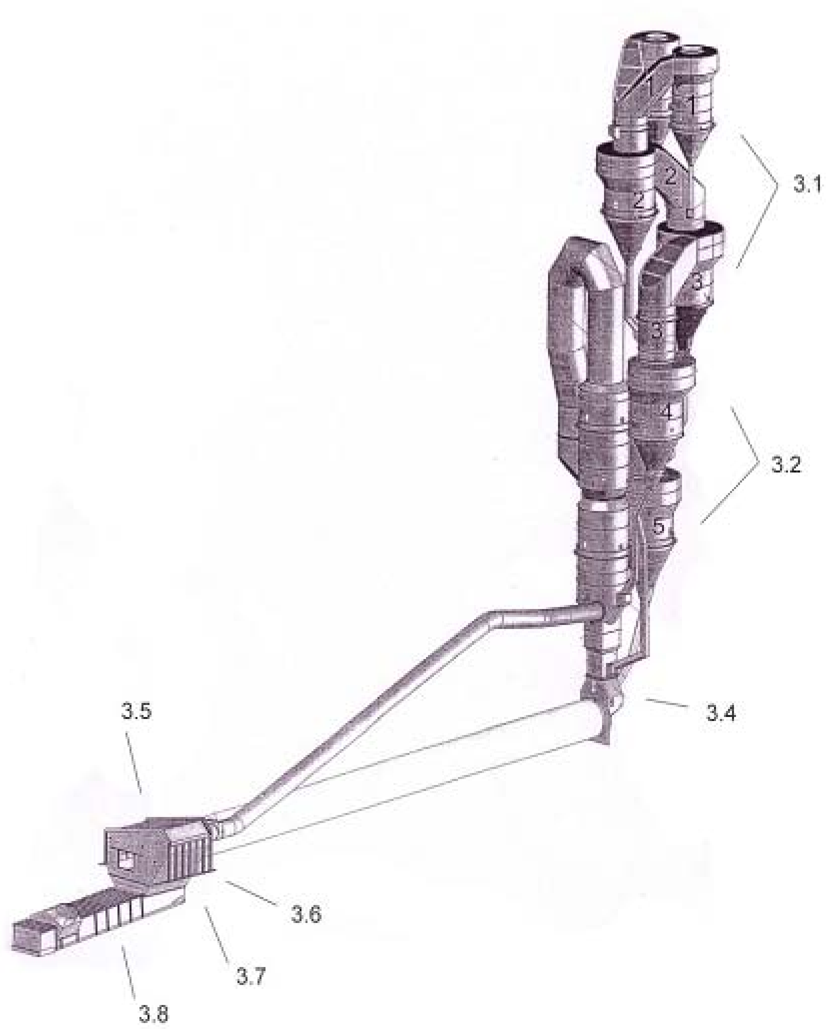

Fig. 1: Diagram and sections of a cement kiln line

3.1 Exchanger system, upper area

The term “upper area of the exchanger system” includes cyclones the C-I … C-III, smoke channels (uptakes), channels K 2-1 … K 4-3 and raw material chutes from these cyclones. The work temperatures in these areas move from 300 to 500°C. When the unit is properly operated, there are no influences relating to the combustion of alternative fuels. The passing cement raw material prevents the undesirable products from penetrating into these places. The lining can be damaged only by mechanical wear, mainly by abrasion. Repairs are usually made in these parts after several years of operation.

Burnt fireclay building materials, with Al_2O_3 content up to 40% are largely used for the lining in these sections. As well gunning refractory concretes can be used in working layers because there are practically no chemical attacks in these zones.

Therefore common dense gunning refractory concretes can be used here (2 kinds ***E***,***F*** from Table 2).

3.2 Exchanger system, lower part

The lower exchanger system usually includes the lowest cyclones (C-IV and C-V), calcination chamber and RISER. The influence of alternative fuels, primarily products from their thermic decomposition, is significantly higher in these areas. It depends on the place where these fuels are dosed, on fuel kinds and possible combinations and burned quantity. There are significantly higher combustion temperatures (800 - 900°C, even 1000°C) in these zones. Mainly harmful substances are localized here that can originate directly here or get into through the rotary kiln from the main burner.

They cause:

- chemical corrosion of linings
- corrosion and phase changes of heat-resistant steel
- they contribute to the higher build-up formation.

As for refractory concretes, LCC refractory concretes are used in these areas, they are installed trough vibration casting. They are declared as alkali-resistant, which means that they do not show so-called *alkalibursting* (which is identified in the designation with *„RA"*). The basic types ***I***, ***J*** are from Table 3. Refractory concretes with a silicium carbide portion practically prevail here. SiC has several benefits in refractory concretes. Thanks to the layer oxidation on the brickwork surface, it closes pores and reduces penetration of harmful substances into the lining. Besides, it prevents from the build-up formation because the strength of the build-up - lining connection is significantly lower. Our universal refractory concrete is the type ***M*** with 25% SiC. Where the build-up formation is noticeable, we install refractory concretes with even higher SiC content up to 55%, i.e. the kinds ***N***,***O***.

Common gunning refractory concretes are generally not recommended for these sections of the kiln line, however for time reasons the whole lining cannot be installed through casting and so the gunning process is used. The refractory concretes, which offer year-long lifetimes, are the types ***G,H***. The novelty is LCC spraying of refractory concretes (type ***Q***). However, values comparable with the vibration installation are so far problematic. Besides, special modified nozzles and very high-quality operators are required. But this is the way of the leading refractory manufacturers.

We use pre-manufactured refractory concrete fittings tempered to 600°C for some of the most problematic parts, such as leading edges of the lower cyclone, calciner parts etc. This solution is more expensive, but the complicated drying is abandoned, the installation process is quicker and no complicated molding is required. Besides, the processing quality of the refractory concrete block in the plant is often at a higher level than in case of on-site installations made often under bad climatic conditions.

Lately LCC refractory concretes based on allumine alumosilicate – silicium carbide - ZrO_2, e.g. type ***P***, are installed in these kiln sections. The excellent chemical resistance of zirconium compounds is utilized here. SiC is used in lower concentrations, which eliminates some of its negative properties, such as possible oxidation under higher temperatures and follow-up bending of lining blocks, and also its very high heat-carrying capacity.

Even though the development never ends, we can say that the new introduced refractory concretes can show long-time lifetimes even in these demanding zones. However, until now the anchorage system of the monolithic linings is a considerable and not solved problem. There are various quality steel grades, anchor thicknesses and profiles tested, ceramic anchoring components are combined etc.

It is often necessary to repair a lining because the anchor system is degraded even if the working surface of the refractory concrete lining is in a very good condition, often practically intact. One of the ways, in addition to the searching of more suitable steels, is a better cooling system of steel anchors.

It proves that is it not fully suitable to use calcium silicate or fibrous boards for the rear insulation. The anchor in this arrangement is insufficiently cooled due to the bad heat transfer between the anchor and the insulating material. The anchor is permanently heated to high temperatures, which speeds up its thermic and chemical degradation.

It is much more suitable to make the insulation from the insulating refractory concretes. They are primarily gunning mixtures. Instead of the types ***A, B, C, D*** given in Table 1, heavier and more conducting materials are used lately (volume weights up to $1.3 kg/dm^3$). Even sophisticated solutions are known, where the insulation is made only between the anchors and the anchors themselves are completely concreted around with dense refractory concrete of the working surface.

3.3 Hot-Disc

It is a special plant to burn various kinds of alternative fuels both in liquid and solid form. The plant is placed between the footing piece and the calcinations channel in the section that is sometimes called „Riser“. Considering the wide spectrum of the burned fuels, their various quantities and combinations, the refractory lining can be largely damaged and therefore it is usually restored in the range of 50-60%. The following adverse effects show here: chemical corrosion caused by products of decomposition of alternative fuels, abrasion given by quick flowing of the filling in the plant and also by erosion on the contact of the rotary floor disc and walls, then occasional local extreme increase of temperature due to variation of the heating value of dosed wastes and relating temperature changes.

A refractory material is selected that would resist at least 1 year of operation, likewise the rotary kiln lining. There are used various kinds of refractory concretes used in various parts of the Hot-Disc. This is the alkali-resistant vibration type ***J*** in upper sections that are not submitted to corrosion, or the self-flowing type ***K*** in uneasily accessible places. This year we have applied the refractory used in the waste incinerators in lower parts of the walls, the type ***R*** from Table 4 (ULCC based on corundum, with CrO_2 and zircon portions). The segments connected with the floor were pre-manufactured from the same material.

3.4 Footing piece

The footing piece of the cement lines is one of the most important parts. All possible influences affect the lining here, from chemical influences through high temperature stress up to strong abrasion, dynamic stress from air guns and from the rotary kiln itself. In case of a failure of the plant, the lining gets a temperature shock where the highest temperature of the exchanger system occurs.

In constructional respect, it is one of the most segmented places with various holes that divide the integrity of the lining into small parts that can be bricked up only in a monolithic way. After one-year operation, it is usually necessary to repair the tongue, side walls and arches. The arch is usually not repaired because the refractory concrete is damaged, but because the bearing steel structure is over-burned and it is necessary to replace the lining together with the structure. Considering the high temperature, boards from ceramic fibers with the classification temperature 1260°C are used here, and also the above mentioned insulating refractory concretes. Cast LCC refractory concretes with SiC portion from 15 to 40% are used for the work linings.

Tempered refractory concrete fittings in the quality ***M*** were applied in some of the footing pieces, however their portion did not exceed 15% of the surface of the other linings. The reason is both simpler installation of monoliths and the above mentioned segmentation of the linings.

3.5 Heat head and tertiary air channel

The heat heads are classified depending on their design as heads with an extract for the tertiary air channel or heads with an extract to the cooler. The classical design of the heat heads uses a minimum quantity of cast and gunning refractory concretes and refractory concrete pre-manufactured fittings. It is primarily given by their geometry.

In case of heat heads with the tertiary air extract, the lining is designed as a monolith, in addition to the hinged top. There are problematic places around the inlet of the rotary kiln and the inlet of the tertiary air channel.

There was no chemical corrosion in the heat heads until recently. However, we can notice corrosion influences also in these sections due to the increased use of alternative fuels and their dosing through the main burner. Thanks to these influences, it is used LCC alkali-resistant refractory concretes ***I, J***, occasionally the material ***L*** with a small allowance of SiC. There is a damper in the air channel. This damper is exposed to abrasive wear by the flowing clinker dust and temperature changes. The bauxite LCC refractory concrete ***T*** with a small allowance of SiC proved suitable.

3.6 Output ring of rotary kiln

The output ring of the rotary kiln is not significantly affected by the alternative fuels, but it suffers from abrasion of the flowing clinker and too big temperature stress. Basically, our standard material for this purpose is the LCC refractory concrete of type ***M*** with 25% SiC. Lately we monitor refractory segments with the allowance of up to 6 weight % of needles from heat-resistant steel (so-called dispersed microreinforcement). The results show the reliable lifetime up to 2 years. However, the output ring is often removed already after 1 year of operation, even though it is not fully damaged. The reason is the complete burning and degradation of surrounding metal parts.

3.7. Burner

The main burner is covered with a protective refractory concrete hull over the total length, usually in the thickness from 60 to 100mm. After the alternative fuel dosing was introduced, the lining is chemically attacked over the total length inserted in the kiln. The burner point suffers most of all, also from dynamical vibration, temperature differences, different thermal expansivity of the metal inside and the refractory

concrete case. This point is often designed as replaceable, long slightly over 100cm. Present lifetimes reached by our firm are about six months for the point (zircon-mullite ULCC refractory concrete ***U*** with steel needle allowance) and two years for the other part (alkali-resistant LCC refractory concretes ***J, M***).
It is advantageous to make the concrete work at least near the point at the manufacturers of the refractory concrete fittings because it is possible to secure the first perfect temperation relating to the safe removal of the used water.

3.8 Grate cooler

The raised floors (i.e. protective walls) of the grate cooler are stressed at most. There are high abrasion and considerable temperature shocks caused by the huge quantity of the blasted cooling air underneath through the grate. There are several types of refractory concretes (***T, X***) are used for repairs. Compounds with polypropylene micro fibers are applied to secure safer drying because it is known that the control drying of the cooler itself is difficult. The molten polypropylene micro fibers leave micropores, through which the steam can easily leak. Pre-manufactured and tempered blocks proved successful for the linings of the raised floors. Their larger use is hindered by their higher prices and complicated design, replacement and attachment.

The monoliths are often used for linings of walls and inclined workings where the clinker falls into the cooler. Long-time lifetimes are reached using abrasion resistant bauxite refractory concretes with SiC allowance, e.g. ***T***.

The cooler top is always made from hinged burnt fittings. The refractory concrete fittings are only suitable for the most stressed section (bull nose). Lately we have applied alkali-resistant refractory concretes with increased resistance against temperature shocks, types ***V, W.***

4. Installation of refractory monoliths under extreme climatic conditions

The refractory linings are mainly repaired in the period when the cement sale is low, i.e. in the winter season. As the installation process of refractory monoliths is a wet technological procedure, many complications occur under low temperature below the freezing temperature. In spite of that, the installation of refractory monoliths runs under these conditions as well.
It is necessary to observe several conditions for successful sequence of work:
a) Use refractory concrete compounds made for the winter season;
b) Use newly made compounds; every week from the production (mixing) date of a dry refractory concrete compound is important;
c) Before installation, store pallets with dry refractory concrete compounds ideally 48 hours in a heated area and then transport them to the workplace immediately before their processing;
d) Use warm water;
e) If it is technically possible, protect the new concreted block of the lining with any insulation against cooling, until the fastening is completed;
f) Use heating apparatus to heat new concreted monoliths.

5. Conclusion

The presented contribution covers the present level of refractory monolithic linings of kiln lines both in material and composition respect. The frequency of the used materials is based on various conditions in the individual cement factories where there are different kiln line constructions and also their output capacities, raw materials for clinker production, quantities and compositions of alternative fuels, which influences operating conditions of refractory concrete linings. Even though some individual conditions in the cement kiln can be simulated in laboratories and the refractories can be pre-tested, the complex impact on the linings and the suitability of the composition can be showed only during operation in the kiln line.

6. Literature

[1] Publication of Union of cement production, SR, 2007
[2] Stone,N.; Tran,T.; Wright,W.W.; Hay.D.; Rockelmann,N.: Alkalic corrosion of refractories suitable for transfer chambers of cement kilns, UNITECR, 1999
[3] Barta,P.; Södje, J.: Wear of refractories of cement rotary kiln heated with waste fuels (Part I.II.), Silika 2003 a 2004

Table 1: Insulating castable for linings of cement kilns

Dry castable mix			**IZOBET 1050/0,85T**	**IZOBET 1100/0,9T**	**IZOBET 1150/1,0T**	**IZOBET 1200/1,3T**
Tag of castable			***A***	***B***	***C***	***D***
Type of castable			ICG	ICG	ICG	ICG
Main raw material base			perlite	perlite	haydite	fireclay, perlite
Classification temperature		°C	1050	1100	1150	1200
Al_2O_3		%	30	37	30	35
SiO_2		%	37	34	43	44
CaO		%	19,5	22	13,5	10
SiC		%				
ZrO_2		%				
Mixing water		l/100kg	nozzle	nozzle	nozzle	nozzle
Bulk density	110°C	kgm^{-3}	860	880	1030	1360
	800°C	kgm^{-3}	790	800	980	1300
	KT°C	kgm^{-3}	780	830	980	1300
Cold crushing strength	110°C	MPa	4,0	5,5	3,5	7
	800°C	MPa	3,0	3,2	3,0	5
	KT°C	MPa	1,5	1,8	2,0	4
Apparent porosity	800°C	%	60	56	45	40
	KT°C	%	68	65	55	45
Permanent linear	800°C	%	-0,5	-0,8	-0,3	-0,2
change	KT°C	%	-1,0	-1,7	-1,0	-0,5

Shortcuts: *KT* - Classification temperature

Table 2: Dense gunning castables for linings of cement kilns

Dry castable mix			**ŽÁROBET TOR-1200-plast**	**ŽÁROBET TOR-1300-plast**	**ŽÁROBET TOR-1400-plast**	**ŽÁROBET TOR-1400-SIC-25**	**NOVOBET TOR-1400-SIC-ZR-RA**
Tag of castable			***E***	***F***	***G***	***H***	***Q***
Type of castable			DG	DG	DG	DG	LCC-G
Main raw material base			fireclay	fireclay	low iron fireclay	low iron fireclay, SiC	low iron fireclay, SiC, zircon
Classification temperature		°C	1200	1300	1400	1400	1400
Al_2O_3		%	34	38	46	32	35
SiO_2		%	45	44	39	29	39
CaO		%	9,5	9,5	10	9,5	2,5
SiC		%				25	9
ZrO_2		%					10
Mixing water		l/100kg	nozzle	nozzle	nozzle	nozzle	nozzle
Bulk density	110°C	kgm^{-3}	2050	2060	2060	2210	2310
	800°C	kgm^{-3}	1970	1950	1920	2070	2380
	KT°C	kgm^{-3}	1960	1900	1900	2100	2320
Cold crushing strength	110°C	MPa	50	55	75	60	55
	800°C	MPa	35	50	55	45	55
	KT°C	MPa	15	25	40	30	50
Apparent porosity	800°C	%	29	25	27	26	16
	KT°C	%	28	27	28	24	16
Permanent linear	800°C	%	-0,3	-0,2	-0,2	-0,2	-0,2
change	KT°C	%	-1,0	±0,8	+0,9	±0,4	-0,5

Shortcuts: *KT* - Classification temperature, *RA* - alkali resistant, *HT* - thermal-shock resistance

Table 3: Low cement castables for linings of cement kilns (part 1)

Dry castable mix			**NOVOBET 1350-RA**	**NOVOBET 1450-RA**	**FLOBET 1450-RA**	**NOVOBET 1500-SIC-10-RA**	**NOVOBET 1400-SIC-25-RA**	**NOVOBET 1400-SIC-40-RA**	**NOVOBET 1500-SIC-55-RA**
Tag of castable			***I***	***J***	***K***	***L***	***M***	***N***	***O***
Type of castable			LCC	LCC	SFC	LCC	LCC	LCC	LCC
Main raw material base			fireclay	low iron fireclay	low iron fireclay	low iron fireclay, SiC	low iron fireclay, SiC	low iron fireclay, SiC	SiC, al-silicate
Classification temperature		°C	1350	1450	1450	1500	1400	1400	1500
Al_2O_3		%	36	40	39	43	32	26	19
SiO_2		%	49	50	47	41	37	28	20
CaO		%	1,8	1,8	1,8	1,8	2	1,8	1,8
SiC		%				10	25	40	55
ZrO_2		%							
Mixing water		l/100kg	5,2-5,8	5,6-6,2	6,8-7,3	5,8-6,4	5,5-6,0	5,8-6,4	6,0-6,6
Bulk density	110°C	kgm^{-3}	2250	2280	2230	2320	2280	2330	2420
	800°C	kgm^{-3}	2220	2260	2220	2300	2260	2300	2380
	KT°C	kgm^{-3}	2200	2290	2260	2280	2220	2250	2370
Cold crushing strength	110°C	MPa	80	80	45	65	65	60	80
	800°C	MPa	90	90	45	80	85	85	90
	KT°C	MPa	80	100	100	70	60	40	80
Apparent porosity	800°C	%	13	13	14	14	14	16	16
	KT°C	%	12	11	13	14	15	16	16
Permanent linear	800°C	%	-0,2	-0,2	-0,2	-0,2	-0,2	-0,2	-0,1
change	KT°C	%	+0,4	-1,1	-1,0	-0,5	+0,7	+0,9	+0,6

Shortcuts: *KT* - Classification temperature, *RA* - alkali resistant, *HT* - thermal-shock resistance

Table 4: Low cement castables for linings of cement kilns (part 2)

Dry castable mix			**NOVOBET 1450-SIC-ZR-RA**	**ULTRABET 1700-KZCr**	**NOVOBET 1550-B**	**NOVOBET 1600-B-SIC-10**	**ULTRABET 1700-ZM**	**NOVOBET 1450-SIC-15-RA-HT**	**NOVOBET 1600-B-SIC-10- HT**	**NOVOBET 1650**
Tag of castable			***P***	***R***	***S***	***T***	***U***	***V***	***W***	***X***
Type of castable			LCC	ULCC	LCC	LCC	ULCC	LCC	LCC	LCC
Main raw material base			AS, SiC, ZrO_2	corundum, Cr_2O_3, zircon	bauxite	bauxite, SiC	zirconmullite. mullite	low iron fireclay	bauxite, SiC	high alumina fireclay
Classification temperature		°C	1450	1700	1550	1600	1700	1450	1600	1650
Al_2O_3		%	32	85	75	2900	63	36	73	72
SiO_2		%	41	7	15	2890	24	42	8	23
CaO		%	2	0,7	2,5	2860	0,7	2	1,8	1,3
SiC		%	9	2 (Cr_2O_3)		10		15	10	
ZrO_2		%	10	3			9,5			
Mixing water		l/100kg	5,4 -6,0	4,0-4,5	5,0-5,6	4,5-5,0	4,0-4,6	6,0-6,5	5,0-5,5	4,5-5,0
Bulk density	110°C	kgm^{-3}	2360	3150	2710	2900	2640	2280	2850	2620
	800°C	kgm^{-3}	2350	3090	2660	2890	2610	2270	2840	2560
	KT°C	kgm^{-3}	2400	3130			2660	2270		2550
	1500°C			3130	2670	2860	2610		2810	2510
Cold crushing strength	110°C	MPa	70	50	100	75	50	80	75	70
	800°C	MPa	75	90	105	110	70	90	100	100
	KT°C	MPa	75	150			130	85		110
	1500°C			150	90	90	120		90	120
Apparent porosity	800°C	%	14	12	16	13	11	14	14	13
	KT°C	%	13	12			12	14		13,5
	1500°C			13	17	15	14		16	16
Permanent linear	800°C	%	-0,2	-0,2	-0,2	-0,2	-0,1	-0,2	-0,2	-0,2
change	KT°C	%	-0,8	-0,5			-0,4	-0,6		+0,7
	1500°C			-0,4	+0,4	-0,3	-0,3		-0,4	+1,0

Shortcuts: *KT* - Classification temperature, *RA* - alkali resistant, *HT* - thermal-shock resistance