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Imerys Kiln Furniture

Energy Saving Through Materials Development

APTALITE®: A novel light weight cordierite designed for roofing tiles Applications

Abstract

A novel structural cordierite ceramic APTALITE [1,2], with a 20 % reduced specific density is presented as a contribution to reduce the energy consumptions in roofing tile firing. This ceramic has been specifically tailored to be applied as H-cassette kiln furniture in order to meet the essential thermo-physical characteristics for a long service life. The characteristics are achieved by a microstructural re-design of the cordierite ceramic. Although the specific density of the cordierite ceramic is reduced, the material keeps the mechanical strength, high temperature creep resistance and thermal conductivity as well as thermo shock properties in the required ranges. The material is produced by traditional slip casting on a production scale and is runs presently through industrial application tests in various roofing tile production lines to proof the performance durability. After the first six-months the Aptalite cassettes show fully compatible performances in comparison to standard cassettes.

DENSITY	[g/cm]³	1,85
WATER ABSORTION	[%]	14,66
POROSITY	[%]	27,18
MOR $_{20°}$	[MPa]	19,49
MOR $_{1200\,°C}$	[MPa]	10,8
CTE $_{RT - 1200°C}$	[10^{-6}/K]	2,10

Tab. 1 Physical properties of Cordierite ceramics for roofing tile applications (Aptakorit ZSA)

Introduction

Kiln furniture in roofing tile Firing

The energy consumption in modern roofing tiles factories is approximately 223 000...297 000 kJ/t [3] and represents a quite major factor of the production costs. It is a self speaking commitment of Imerys, which is a roofing tile manufacturer as well as a kiln furniture producer, to consistently work on systems and new developments to reduce the energy consumption, here not just for the reduction of energy costs but for the sake of our environment and ecological balance. In this sense a considerable mass reduction of kiln furniture systems in today's roofing tile production is one of our contributions.

For Europe the H-cassette kiln furniture represents the most commonly used setting system for roofing tiles followed by the U-cassettes, which are more broadly used in Southern Europe and Asia. A typical roofing tile factory uses approx. 60 000... 80 000 pieces of H-cassettes to produce 21 x10^6...28 x 10^6 roofing tiles per year [3], whereas the mass ratio roofing tile versus H-cassette is approx. 1 : 1,5 [3]. The reduction of 10 % of kiln furniture mass is equivalent of an approximate reduction of the energy consumption of 2,5 %...5 % in roofing tile production depending on the used kilns and firing conditions. This is equivalent to a reduction of 631 x 10^6...841 x 10^6 kJ/a, which corresponds to 522...697 t CO_2/a per kiln respectively [3].

Fig. 1 Exemplary accessory H-cassettes

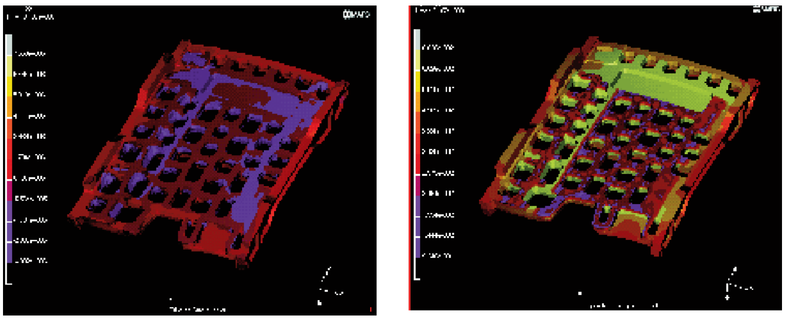


Fig. 2 Thermal stress distribution of an exemplary H-base cassette during abrupt temperature changes through FEM model

Cordierite ceramics as roofing tile kiln furniture

The work horse in kiln furniture for roofing tile firing is cordierite ceramics (Tab. 1) This material represents as kiln furniture for roofing tiles an optimum balance in

- sufficient thermo-physical properties
- excellent service life
- production costs.

It is particularly the outstanding thermal shock resistance due to an extremely low coefficient of thermal expansion, which makes cordierite ceramics a predestinate material for kiln furniture application under thermo-cyclic conditions.

The relatively low modulus of rupture and the cordierite decomposition temperature at approximately 1420°C limit the material in terms of mechanical loads and maximum application temperatures respectively. Roofing tile firing temperatures are within the applicable temperature range for cordierite and the present H-cassette technology does not require mechanical strengths beyond the given range, but, on the other side does not leave too much room for further reduction either.

Tailored design solutions

Cordierite H-cassettes and U-cassettes are tailored kiln furniture designs. Each roofing tile shape and accessory requires an individual design of cassettes to find the optimum in terms of

- precise geometric support for the roofing tile during firing
- service life
- mass

It is essential that experienced design teams provide tailored solutions for the clients to combine the typical characteristics of the material with an adequate ceramic design to achieve and eventually guarantee these targets. Fig. 1 shows some typical H-cassette designs for base tiles and accessory tiles, whereas Fig. 2 illustrates an example of a FEM analysis that models the thermal stress distribution of the cassette during abrupt temperature changes in the cooling zone, which is a mandatory tool in the professional design of such complex geometries. Cordierite H-cassettes have a typical service life of 1500 -3000 firing cycles. The limiting life time factors of the cassettes arise from damages coming from automated loading- and unloading systems, and excessive feet-chipping would lead to a replacement of the product. Another life time limitation arises from chemical corrosion of aggressive condensates that may lead over an extended period of time to changes in mineral phase compositions and thus losses in mechanical performances.

Production technologies

The most common production process of cordierite H- and U-cassettes is slip casting, since it allows the relatively highest design flexibility in ceramic shaping technologies. The applied cordierite slip casting technologies at Imerys kiln furniture are

- standard slip casting without externally applied pressure
- low pressure casting [4]
- high pressure casting.

Dry pressing technologies are also applied, but this process is typically limited in design flexibility. The dry pressed cassettes tend to be heavier then casted cassettes.

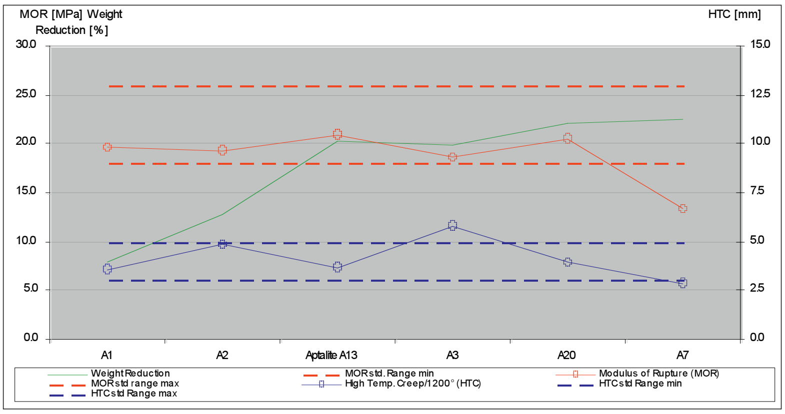


Fig. 2 Mass reduction, MOR and HTC of cast cordierite compositions

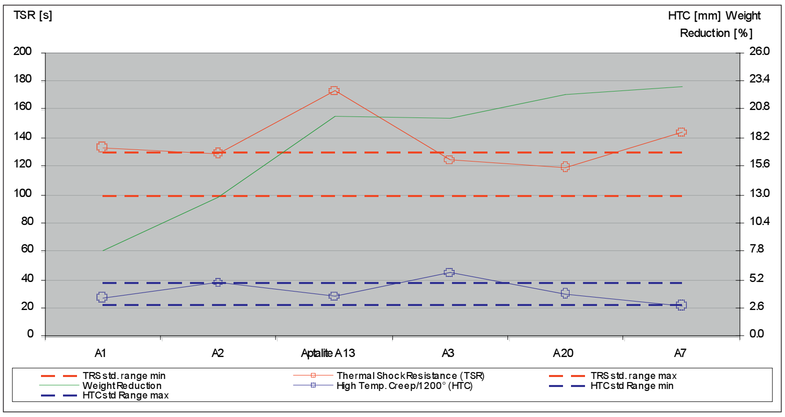


Fig. 3 Mass reduction, TSR and HTC of cast cordierite compositions

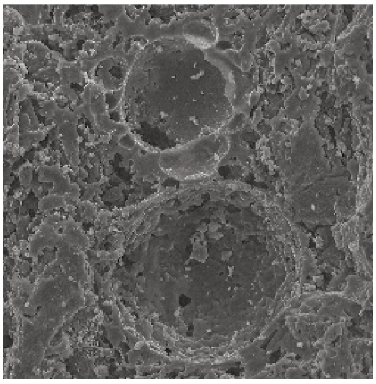
Alternative high-end SiC materials

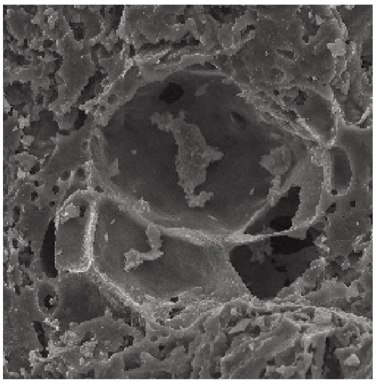
Alternative kiln furniture materials such as high end SiC ceramics are certainly applicable and various design version of low weight SiC H-cassettes have been proposed earlier. A mass reduction of 40 % would be achievable, long service periods can be expected. However, the production costs of weight reduced e.g. SiSiC-H cassettes are a multiple of cordierite H-cassettes and can simply not justify their applications as alternative H-cassette material from a purely economical point of view.

As a consequent step, the reduction of the specific density of the cordierite ceramics as such would be the most pragmatic approach. Lighter H-cassettes could be directly implemented into the running roofing tile production plants without

Tab. 2
Physical Properties of test series for light weight cordierite

Sample Code	Unit	Standard	A1	A2	A3	A7	Apalite A 13	A 20
Waterabsorption	[%]	14,6	18,9	21,6	26,7	23,2	25,6	28,6
Density	[g/cm^3]	1,89	1,74	1,65	1,52	1,46	1,51	1,47
Porosity	[%]	26,9	32,8	35,5	40,5	34,0	38,9	42,4
Modulus of Rupture (MOR)	[MPa]	24	19,7	19,3	18,7	13,4	20,9	20,6
Thermal Shock Resistance (TSR)	[sec]	100--120	133	129	124	144	173	119
High Temp. Creep/1200° (HTC)	[mm]	3,20	3,56	4,85	5,79	2,84	3,66	3,94
Mass Reduction	[%]	---	7,9	12,8	19,9	22,8	20,1	22,2





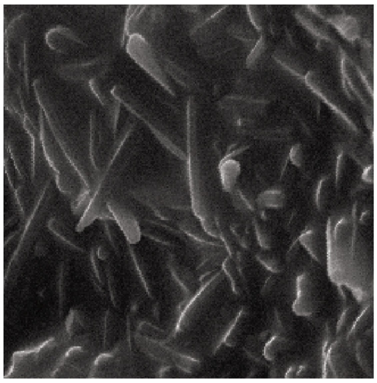


Fig. 5a (left)
Fracture surface of Aptalite with imbedded hollow microspheres (SEM, 5 mm bar = 33μm)

Fig. 5b (middle)
Fracture surface of Aptalite with imbedded hollow microspheres (SEM, 5 mm bar = 20μm)

Fig. 4c (right)
Fracture surface of Aptalite, details of imbedded microsphere surfaceshowing crystallized Mullite needles (SEM, 5 mm bar = 1μm)

any adjustments but reduced energy consumptions.

Target of APTALITE®

The challenge in the new material development was to achieve a mass reduction of up to 20 % but keeping the mandatory materials properties within the required range as indicated in Tab. 2.

- to assure fully sufficient heat transfer from the H-cassette support to the fired product
- be proofed in industrial tests
- produce the new material by slip casting processes
- proof the industrial durability of the new material in a roofing tile plant under production conditions, i.e. compatibility of light weight cordierite cassette versus standard cordierite material.

State of the Art

Mass reduction in ceramics is commonly applied. Here the main target is mostly the reduction of thermal conductivity particularly in building materials and in refractory products. The introduction of organic components is a standard procedure in heavy clay brick manufacturing, which eventually burn out during the firing process. The remaining mostly alkaline residues in the final product are acceptable for the final application. Refractory applications commonly refer to introduce hollow refractory spheres that are introduced into the body mixes used for pressing [6] or in the case of monolithic into the cement bonded castable [7] or phosphate bonded castable [8].
Recent developments on low weight cordierite materials have been reported, in which the density has been reduced down to 1,1 g/cm³, however, the MOR has also severely dropped. The application as a kiln furniture is thus recommended to be limited to very low mechanical loads [9]. The original purpose of kiln furniture to transfer heat to the e.g. tableware product in the firing process is likely to be significantly reduced. Thermally insulating materials may only be used as super structure elements that are not in touch with the fired goods, e.g. kiln car base.
The focus of all these materials is to achieve high thermal insulation properties. Mechanical properties are of less importance and the reductions of the reported MOR are significant. On the other side, structural kiln furniture systems usually refer to high-end SiC ceramics such as SiSiC, RSiC, NSiC and SSiC, which lead to significant mass reduction due to their relatively higher mechanical strength and possible downsizing of the loaded cross sections of the structural elements [10]. However, the approach to reduce the specific density of structural cordierite kiln furniture ceramics is apparently new and has so far not been published in the public domain literature.

Development Approach

The key properties of Cordierite ceramics are determined by the bonding matrix. The appropriate balance of mechanical strength, high temperature creep resistance, thermal shock resistance is decisive of the durability of the H-cassette under the typical thermo-cyclic conditions. Furthermore the increase of the porosity in kiln furniture that is in direct contact with the fired good is limited since the heat transfer to the product is essential, i.e. a thermal insulator can simply never be a good kiln furniture.
Coarse grain aggregates are imbedded in the actual Cordierite matrix and considerably affect the thermal shock properties of the final product, so in principle the basic rules of refractory microstructure design can be applied.
Considering the slip casting process, a simple introduction of some low density organic and/or inorganic additives into the ceramic slip will typically lead to segregations in the slip and consequently results in inhomogeneous material properties, which are not acceptable for structural applications.
Therefore the main focus is to

- tailor a novel cordierite microstructure resulting in the required high durable matrix properties but allowing a total mass reduction of up to 20 %
- transfer the novel compositions to a stable slip casting process applicable in the high volume production requirements.

The function of the individual microstructural components, their cross functions as well as the complex in-situ reactions are elementary in the design of a novel microstructure, which requires comprehensive pre-studies. With this a differentiation of active and passive components can be obtained. Coming from this basic approach the introduction of chemical- and mineralogical compatible but low mass passive components is a logical step [1]. Thus the introduction of tailored ceramic microspheres on a pure mullite basis as passive microstructural components has been thoroughly investigated.

Test methods

MOR was measured on samples 290 x 20 x 10 mm³ as 3-points bending test with a span of 120 mm on a Metefem Bending Tester XP-01; type MH-1 / AS 102. Thermal shock resistance was tested on samples 290 x 130 x 10 mm³. The samples are placed in horizontal position in a distance of 95 mm over an open flame generated by a common pilot burner. An Ni/Cr -Ni thermocouple control the flame temperature on 940 °C. Time in seconds is registered, until visible cracks appear or the sample breaks. High tempera-

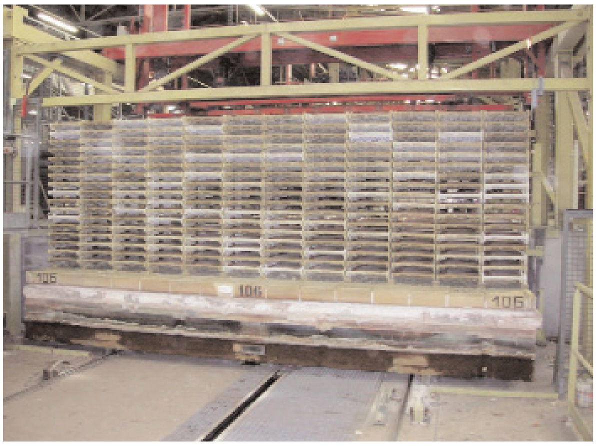


Fig. 6a Industrial test of Aptalite. Aptalite cassette (white) irregularly placed onto a kiln car.

Fig. 6b Industrial test of Aptalite: marked Aptalite among standard IKF-cassettes on a kiln car.

ture creep was tested on bars 290 x 25 x 10 mm.
The samples are supported under each end in a distance of 250 mm and loaded with a mass corresponding to a stress of 0,5 MPa. The samples are fired at 1200 °C with a soaking time of 10 h, and deformation is registered.

Results

The implementation of ceramic microspheres as passive components into the slip casting process has been successfully achieved and leads to the required range of density reductions. Without the intention to discuss details of the development of the materials and the slip casting process, the eventual outcome of the work leads to a series of new material compositions and –properties (Tab. 2, Fig. 3, 4). The graphic illustrations in Fig. 3/4 underline that the mass reduction and the effect on physical properties are not reflecting a linear correlation in the displayed series. This effect is due to the positive readjustments of the cordierite bonding matrix and lead to a relatively small drop of MOR and just slight increase of the HTC, and here in particular with the A13 series. It should here be underlined that the displayed standard deviations have been obtained under industrial pilot production. In this series the properties of Aptalite A13 represent the relative optimum in mass reduction, MOR, TSR, HTC and low standard deviations. A total weight reduction of 20 % is achieved with moderate effects of the physical key properties. Sufficiently high MOR and HTC within the required limits are achieved. A positive effect can be observed at the increase of TSR, i.e. the microstructure can cope with thermal stress implication better then standard material.
It is therefore expected that Aptalite A13 will show at least a comparable high durability under practical thermo-cyclic conditions versus the standard material. Any further weight reduction beyond the described level leads to an unacceptable reduction of mechanical properties, here in particular the MOR. An increase of chipping along the H-cassette feet would follow. Aside of this, a mass reduction of the cordierite ceramics through additional porosity needs to be properly balanced with its reduced thermal conductivity, a thermal insulator is simply not an appropriate kiln furniture material, being in direct contact with the fired goods.
Figs. 5a-c show exemplary the fracture surfaces of the Aptalite A13 with the imbedded microspheres. The original spherical shape remains geometrically stable and the spheres as such are basically hollow. The spheres have reacted along the original sphere surface with the cordierite matrix components leaving eventually a hollow spherical pore in the cordierite matrix microstructure. Details of the reacted microsphere surface show an intense formation of mullite needle that typically arise from a partially amorphous phase. The cordierite matrix as such with its dominating thermomechanical properties is not further affected by the implementation of the microspheres.
The effect of the increased open porosity of Aptalite needs to be carefully investigated under actual application conditions in roofing tile production plants. The fact that roofing tiles are produced with quite a variation of raw materials leads to a range firing conditions in terms of the highest applied temperature, soak and kiln atmosphere. Furthermore the automated handling mechanisms vary from site to site.

Industrial Tests

A set of approx.1000 H-cassette in the novel Aptalite composition has been produced and implemented in 4 different roofing tile production sites (Fig. 6a-b). The firing condition vary from T_{max} of 1080...1200°C, roofing tile raw material compositions as well a the automated loading and unloading system vary accordingly. All cassettes are used together with standard IKF-cassettes, i.e. identical application conditions.
The cassettes' performance is here directly compared with standard cassettes and all decisive criteria such as chipping, geometric stability, corrosion and mechanical strength are monitored. These tests are still ongoing.
After the first 6 months the Aptalite cassettes have basically a compatible performance as standard IKF-Cordierite cassettes. The product qualities of the roofing tiles are unaffected. Based on the described material data and the very positive performance of Aptalite in the ongoing tests, it is expected that Aptalite will proof its long term performance. The relatively harshest application conditions should eventually clarify, if a performance differentiation will arise in the very long term.

Reference

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