Fiber-Free Ceramic Insulation Foam for Highest Temperatures – a New Generation of HSE-Friendly Refractory Products with Multiple Application Possibilities

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Whereas in the last decades high-temperature and energy consuming processes were insulated using refractory ceramic fiber or insulating bricks, nowadays, increased efforts to save energy, more sophisticated process, reactor design and geometry as well as tightened regulations concerning the use of refractory ceramic fiber have made it necessary to develop an advanced refractory insulating product. Ceramic refractory foam for high-temperature insulating and potential replacement of ceramic fiber or insulating bricks in a wide range of industrial applications is becoming more and more popular; the recent developments in terms of product properties (insulating capability, chemical composition, thermal, mechanical and thermomechanical) are showing that ceramic refractory foams become a serious alternative to the existing solutions. Furthermore, refractory ceramic foams are usually not containing any fiber and are consequently not considered as harmful for human health – complying with law and company internal health policies.
Norfoam® ceramic foam developed by Saint-Gobain can offer a credible and highly efficient insulation alternative to current solutions for temperature above 1200 °C.

1 Introduction

The increasing cost and rapid depletion of conventional sources of energy necessitate effective heat management and energy conservation measures in industrial processes. High-temperature insulation products offer a cost-effective energy management solution for industrial processes. Therefore, OEM, installers and users search for insulating systems that can offer the best compromise between investments, insulation efficiency, energy cost savings, productivity, lifetime and HSE compliance. With respect to properties, the High-Temperature Insulation (HTI) market can be divided into Ceramic Fibers (RCF), biosoluble fibers, Polycrystalline Fibers or Wool (PCF, PCW), and Insulating Firebricks (IFBs). Out of the various HTI material categories, RCFs are the most widely used material, and account nearly 60 % of the market [1]. The low thermal conductivity and flexibility are the main drivers of the demand for this product. However, new REACH regulations are pushing the sector to provide alternative materials to fibers in compliance with the latest HSE standards [2]. On the other hand, IFBs find favoured usage in the furnace applications that require structural properties.
Additionally, the continuous search for yield performance pushes the industrials to operate their processes towards extreme temperatures and consequently creates a demand for high-temperature insulating products with improved performance.
Ceramic insulating foams with their special properties offer a credible and highly efficient alternative to current solutions for temperature above 1200 °C. Although several ceramic insulating foams do already exist on the market, the acceptance of such group of product is still limited to special niche applications as it requires knowledge and help from the suppliers to the users in order to exploit it at the maximum of its potential.
The present article demonstrates the values and benefits of using this new ceramic foam as insulation systems for high-temperature applications and will describe as well in details the performance of the product Norfoam®A, with concrete examples of success applications.

2 Traditional insulation

2.1 Refractory ceramic fiber

RCFs have been used for high-temperature insulation linings in industrials kilns since the early 1950s. The highly desirable properties of RCFs – high thermal efficiency, high heat resistance and high thermal

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shock resistance – resulted in a dramatic increase of their industrial use for a wide variety of high temperature applications (petrochemistry, iron and steel industry, glass production, ceramic production) [1]. In addition, because of its low density and low thermal inertia, the RCF facilitates the control of the temperature inside the kilns and allows faster heating and cooling ramps. The possibility to use such insulating product in different shapes (boards, felt, preformed shapes, modules) spreads its application possibilities widely and enables fast installation, making refractory fiber a first-choice product for high temperature insulation processes.

Ceramic fibers can be divided into 3 categories:

- Alkaline Earth Silicate Wool (AES) consists of amorphous fibers, which are produced by melting a mixture of CaO, MgO, SiO_2 and ZrO_2. AES fibers are generally used for low temperature (<1250 °C).
- Refractory Ceramic Fibers (RCFs) also known as Alumino-Silicate Wool (ASW), are amorphous fibers produced by melting a mixture of Al_2O_3 and SiO_2 (approx 50 : 50 ratio). RCFs are generally used for the temperature greater than 1250 °C and in intermittently operating equipment and critical application conditions. The maximum service temperature of the RCFs differs according to their constituent raw materials; with a limit service temperature around 1300 °C for fibers containing alumina, silica, and kaolin clay; and around 1400 °C for those made of high purity alumina zirconia and silica materials.
- Polycrystalline Wool (PCW) consists of fibers containing mainly Al_2O_3 (>70 mass-%). They are produced by a sol-gel method from aqueous spinning solutions. The water-soluble green fibers obtained as a precursor are crystallized by means of heat treatment. PCW is generally used at application temperatures greater than 1300 °C and in critical chemical and physical application conditions.

Whereas refractory ceramic fibers exhibit a very low thermal conductivity and a very good resistance to severe cycling, some properties are limiting the universal use of refractory fiber.

- Firstly, RCFs are more sensitive to the ablation by the gas, resulting in severe damaging of the material in service. Industrials report that the particle generated by the erosion of the lining is very problematic for their process, with the risks of contamination of their production.
- The chemical inertness of refractory ceramic fibers will depend on the process conditions as alkalis and silicate from the fiber may easily react with in-furnace substances to produce other substance with low melting points.
- Other common drawbacks of these materials is their dimensional instability.

Fig. 1 Norfoam®A boards of 100 mm thickness

RCFs tend to shrink with increased service life with the progress of crystallization. It is commonly known that fiber insulation has been deteriorated with increased service life and operating temperatures, leading to cracks, local thermal bridge formation and potential release again of the product into the process area.

- Refractory ceramic fiber products are no self-supporting systems and therefore not designed to being part of the structural architecture of equipment (e.g. supporting load as sidewall of refractory bricks can do).
- Finally, nowadays, health occupations by industry, producers and new REACH regulations are putting refractory ceramic fibers strongly under focus, as RCFs are considered to be harmful to human organism and probably carcinogenic under certain conditions [3–4]. This evolution is pushing the sector to provide alternative materials to fibers in compliance with the latest HSE standards.

All these aspects limit the accessibility of the ceramic fibers to a full range of high temperature applications, where the ceramic foam products will meet the latest or incoming EHS standards but also offer high added values benefits for industrial processes and end products.

2.2 Insulation refractory bricks

The opposite of refractory ceramic fibers in high-temperature insulation are refractory insulation bricks (also called insulating fire brick IFBs) or monolithic (usually insulating castable or gunning mixes), produced by a bonding reaction of the ceramic compound. IFBs are classified by their insulating performance, which is directly influencing and linked to the chemical composition of the product. Like refractory ceramic fibers, refractory insulating products are used in a wide range of industry sectors and applications, very often in combination. The commonly used insulating fire bricks are in the range of IFB type 23–28, with increase of the range up to type 34 for extreme applications, where the number defines the classification temperature of insulating fire bricks, ranging here from 1260–1840 °C. One main criterion for choosing the right insulating brick is the combination of refractoriness, insulating capability and mechanical strength. The higher the silica content, the lower will be the thermal conductivity. This gain of thermal resistivity will be done to the detriment of the refractoriness, chemical inertness and mechanical strength; thus limiting the usage of IFBs below 30 type to the same range of temperature than the bio-soluble fibers (i.e. 1250 °C).

Insulating fired bricks are generally showing less insulation capability at equal temperature compared to fiber, consequently energy saving purposes may be considered better if fiber products could be used and fit with the design of the apparatus.

Insulating fired bricks are machinable and any shape or design can be performed using the appropriate tooling; but it takes generally more effort to machine bricks rather than fiber because of their existing mechanical strength and high abrasion ability towards the machining tool.

3 Fibers – HSE Regulations

In November 1997, members of the European Union classified RCFs as dangerous products with a Category 1B classification (substances that should be regarded as potentially carcinogenic to man).

On 13 January 2010, the European Chemicals Agency (ECHA) enforced the decision by placing alumina silica wool (Al–Si–RCF and Al–Zr–Si–RCF) on the Highly-Concerned Substances Candidate List, based on the existing classification Category 2 Carcinogenic according to Annex I of the Directive 67/548/EC [3].

Pushed by the market and the evolution of the latest HSE standards, refractory fibers producers have been developing more and more so-called biosoluble fibers, also known as AES fibers. Contrary to RCFs, AES is exempted from carcinogen classification based on short term in vitro study. This type of fibers represents an EHS-compliant alternative for the low temperature range, but their usage is limited to temperatures below 1250 °C.

Up to now, it is still impossible to replace all ceramic fiber insulation by equivalent non-fiber products, taken into account insulating capability, high-temperature service application (>1300 °C), refractoriness, shape and cost. However, more and more customers agree to revise the design of their installations to allow the use of such alternative products and even consent to bare the related costs.

Therefore, there is a clear need for effective, resistant and safe insulating systems for temperature above 1250 °C where bio-soluble fibers (AES) are not suitable or are underperforming.

4 Saint-Gobain Norfoam®

Norfoam® ceramic foam developed by Saint-Gobain can offer a credible and highly-efficient alternative to current solutions for temperature above 1200 °C. The Norfoam® product brand does not contain any fiber material or organics binders and is consequently HSE-friendly in use and application.

Norfoam® products are available as Norfoam®A d0.7, an ultra-pure high alumina version (>99,5 % Al_2O_3). This product range is being completed by two new mullite-based products with improved thermal shock resistance to better address applications subjected to rapid cooling and heating ramp.

Its high refractoriness coupled with its high purity, enable the usage of the product in reducing and strongly corrosive atmospheres. In addition to that, the engineered microstructure provides a thermal conductivity as low as 0,7 W(m·K) at 1200 °C and sufficient mechanical resistance to static loads (up to 6 MPa), providing additional design freedom enlarging the range of possible applications.

The innovative and patented process of Norfoam® using direct foaming allows the production of ceramic insulation foam from a wide range of materials: alumina, mullite, cordierite, and zirconia. This range can be easily extended to non-oxides such as silicon nitride or silicon carbide. The process also enables to produce board shapes with thickness up to 150 mm, never provided by any other ceramic foam suppliers (Fig. 1). Norfoam® has been designed to offer the customer potential alternatives for replacing both refractory insulating bricks and ceramic fiber. It is possible to use Norfoam® where traditional fibers are used, as Norfoam® exhibits excellent machinability, resistance to alkaline or abrasion resistance.

4.1 Engineered microstructure

Thanks to its engineered microstructure, Norfoam® offers advanced properties, insulating capability, thermal shock resistance and high purity compared to insulating fire bricks and refractory fibers. Fig. 2 shows the microstructure of the foam produced by Saint-Gobain. Its microstructure was engineered to provide excellent insulating performance at high

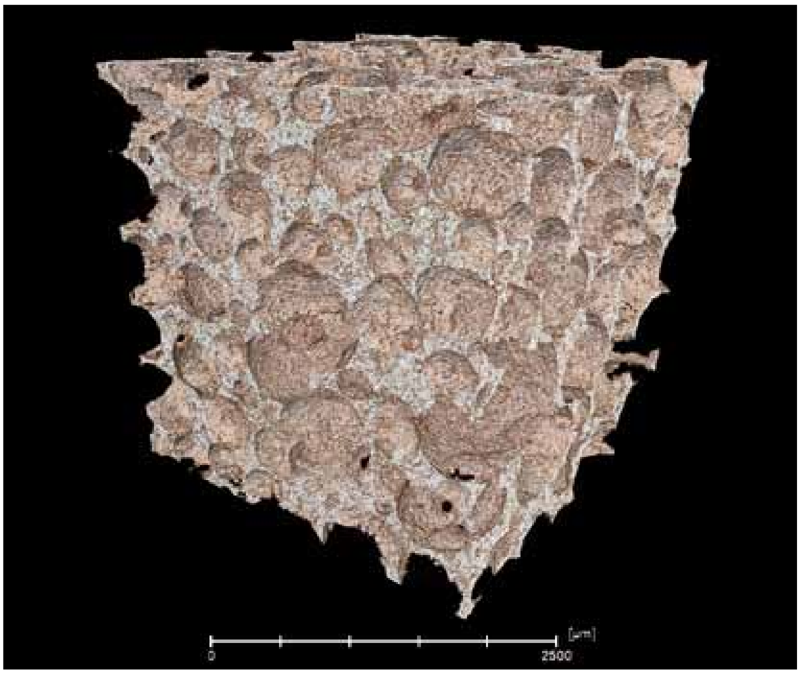

Fig. 2 **3D-X-ray tomography of NORFOAM®A d0.7**

Tab. 1 Norfoam® product properties compared to existing solutions

		Norfoam®A d0.7	IFB Type 34	Fiber Type 184/400
Density [g/cm³]		0,7	1,6	0,4
Total Porosity [%]		>83	50	–
Al_2O_3 [%]		>99,5	98,5	80
SiO_2 [%]		<0,3		
(under Mullite Phase)		0,7	20	
Fiber Containing		None	None	Yes
Cold Crushing Strength [MPa]		6	10	None
Fiber Containing		None	None	Yes
Max. Service Temperature [°C]		1800	1800	1800
Thermal Conductivity [W/m·K]	**400 °C**	0,82	1,70	0,14
	800 °C	0,67	1,30	0,20
	1000 °C	0,69	1,25	0,25
	1200 °C	0,74	1,35	0,29
	1400 °C	0,92	1,45	0,33

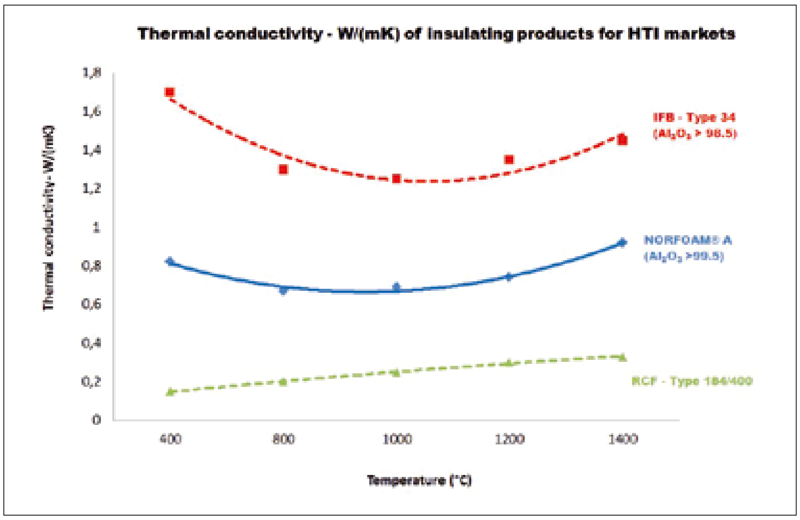

Fig. 3 Comparative thermal conductivity of Norfoam®A, RI34 (IFB) and fiber type 184/400

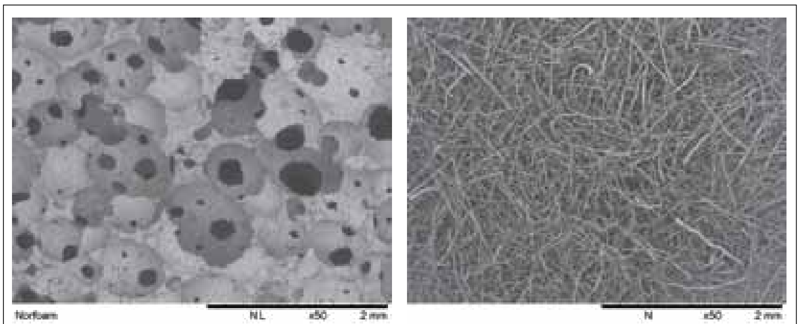

Fig. 4 Microstructure of Norfoam®A d0.7 (l.), and fibers

temperature, while maintaining a sufficient mechanical strength and dimensional stability. The complex architecture of the foams influences their thermal and mechanical properties.

The morphology of the sticks composing the foams varies greatly according to the manufacturing process and the porosity. This compromise microstructure makes the success of Norfoam® enabling to satisfy both the demand for innovative products for HTI markets with high strength and high insulating performance.

4.2 Properties

Tab. 1 shows the main product properties of Norfoam® compared to refractory insulation bricks of type 34 and fiber. The density of the Norfoam® material is significantly lower than that of the refractory bricks with equivalent refractoriness or sufficient mechanical strength in consideration of equivalent bricks stacking.

The density has a significant impact on the thermal insulation capability of an insulating product, which is applicable for both ceramic fibers and bricks. Norfoam® products were designed to provide excellent thermal insulating properties at low density up to a peak temperatures above 1800 °C (Fig. 3).

4.3 Fiber-free

A not negligible advantage of Norfoam® products compared to fibers is of course the absence of any fibers or organic binder, nor in the production process, neither in the product itself (Fig. 4). Users are continuously looking for alternative solutions to replace fiber by non-fiber products as they must comply with the company`s EHS policy or the country regulations. IFBs show only limited potential to replace ceramic fibers because of their relatively high density and weight, limited shape possibilities and insulating performance. Furthermore, Norfoam® products for insulation purpose can be handled like bricks, e.g. using mortar to join them or remove them and recycle the material. Contrary to the refractory fiber demolition, no special caution has to be taken, like confinement of the work zone, protection of workers and environment, special dumping. since no fiber is released in the air.

The Norfoam® product is easier and faster to install compared to a large choice of IFBs as it is lighter in weight and it is available in bigger dimensions. Consequently, maintenance outages, relining or repairs can be made much quicker with less impact on physical constitution of the operating staff.

4.4 Easy machining

Norfoam® has been recognized as one of the best material for machine ability. Indeed, Norfoam® can be easily machined on

site with conventional dry cutting tools or even common wood saw (Fig. 5).
Contrary to fibers, the cutting of the Norfoam® does not release hazardous dust and therefore does not require specific confining process. Thanks to its strong cohesion, the Norfoam® product can be machined with high precision tolerances and very complex designs (Fig. 6). Such a finished quality is hardly achievable with existing solutions either due to its brittleness and friability (Fig. 7).

4.5 Resistance to gas ablation

Norfoam® products are exhibiting excellent erosion and abrasion resistance, making them suitable to be used in zones where high gas speed (even with particle load) or contact with products in motion. Norfoam® products are not deteriorating with time (no shrinkage, no substance release) that may harm the process. Norfoam® is especially suitable for longlife applications, as it does not crystallize as a lot fiber types do and would not crack and release powder on product (e.g. reheating furnace in steel mill or steel coating line).
Gas ablation test performed at 1500 °C for 24 h shows that the product exhibits an excellent resistance to gas ablation equivalent to the highest grade of IFB bricks (type 34, with a density of 1,6 g/cm³) (Fig. 9–10). Contrary to fibers, Norfoam® does not release any particles, therefore avoiding the risks of cross-contamination of in-furnace products. This property allows the use of Norfoam® in a wide range of applications like the white industry.

4.6 Dimensional stability

Based on its long experience in the development of high performance refractories, Saint-Gobain R&D has designed Norfoam® in such way that it can withstand very high temperatures without dimensional variation. Its process has been tailored to optimise the dimensional stability, thus leading to a very limited shrinkage.

4.7 Self-supporting material

Associated to that, the engineered microstructure provides a thermal conductivity as low as 0,7 W/m·K at 1200 °C and resistance to static loads up to 6 MPa. Even though, Norfoam® is characterized by a very low density, its mechanical strength is high enough to

Fig. 5 Examples of cutting with conventional wood saw

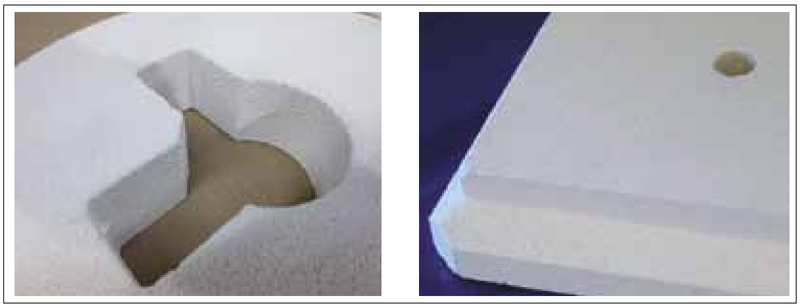

Fig. 6 Norfoam® examples of complex designs achievable by CNC machining

Fig. 7 Comparison of finished quality post-cutting of Norfoam® (l.) vs. IFB bricks 34

Fig. 8 Example of fibers damaged – reheating furnace applications

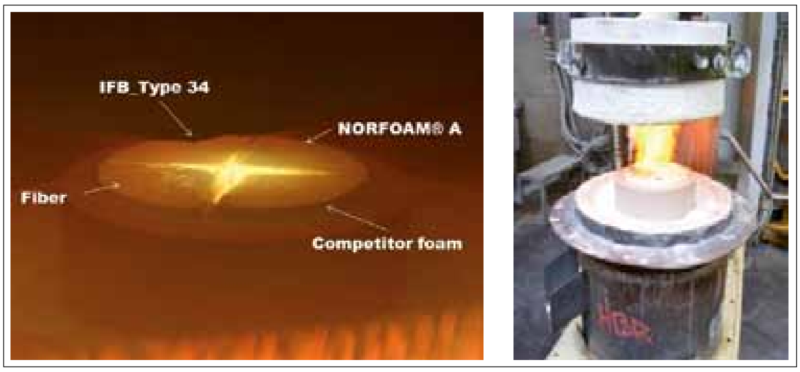

Fig. 9 Ablation test – 24 h/1500 °C (Saint-Gobain internal test)

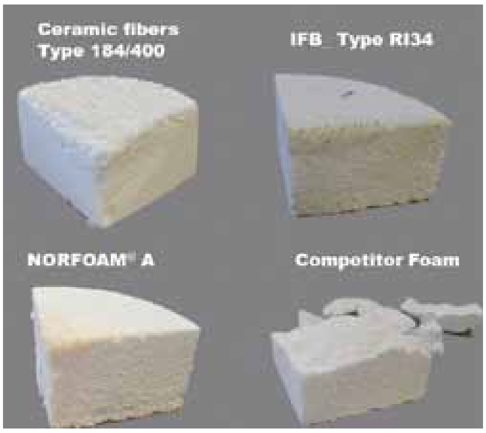

Fig. 10 Insulating products after the ablation test

Fig. 11 Norfoam® in a nitrogen atmosphere furnace

be considered as integral part of the structure of an apparatus. In replacement of insulating bricks, users appreciate the higher insulation performance or the opportunity to reduce the lining thickness. The Norfoam® product also impacts positively the energy balance of the application where it is performed.

The Norfoam® products are exhibiting sufficient mechanical strength, to provide multiple design possibilities, as Norfoam® is suitable to be used as load supporting structure part in apparatus construction. This property can even be enlarged thanks to the superior machinability of the Norfoam® product compared to existing insulating bricks.

4.8 Chemical inertness/ no cross-contamination

Norfoam®A is a high purity foam (Al_2O_3 >99,5 %) that offers new opportunities for insulation in a wide range of applications. Its high refractoriness coupled with its high purity, enable the usage of the product in reducing and strongly corrosive atmospheres. Numerous applications with operating temperatures above 1400 °C require very pure refractory insulating materials to avoid interactions with the process atmosphere or cross-contamination of the in-furnace products by substances potentially released from the refractory lining. The Norfoam®A product is characterized by having a free silica content of <0,1 %, very important for chemical and petrochemical applications operating under hydrogen atmosphere. Norfoam®A has demonstrated its suitability for the aluminium production where its high purity has a real value to avoid the contamination of the products.

Furthermore, at lot of high-temperature treatments cause release of substances into the reactor atmosphere that might react with either free silica or other components of the insulating lining, typically alkaline like Ca, Na or K. Norfoam®A with its high purity helps to prevent these attacks.

5 Application examples

As mentioned before, Norfoam® ceramic foam refractory for insulation and lightweight purpose can be used in different types of industry where high temperature applications are running, like glass making, metallurgy or petrochemical industry. Moreover, all heat treatments or sintering furnaces for technical ceramics or domestic ceramic products are potentially suitable to be lined with such product.

The Norfoam® products are running successfully even under specific atmosphere. Fig. 11 shows the installation of Norfoam® A d0.7 to replace mullite insulating bricks in a furnace running up to 1500 °C under pure nitrogen. Initial lining with insulating product based on sintered mullite was attacked severely by alkalines released from the fired load. These corrosive vapours caused severe damages of the backup layer resulting in occurrence of hot spots on the furnace steel shell. Since installation of Norfoam®A d0.7 boards as replacement, the furnace shell temperature could be reduced and no damage of first and second refractory layer was observed.

Because of their lightweight but high mechanical strength, the Norfoam® products are also used as setters or spacers for firing of a multitude of products. Users are experiencing a faster achievable and more homogenous temperature in the reactor and reduced energy consumption. Different setter types are shown in Fig. 12.

The Norfoam® products are also used in different applications in metallurgy industry, because of their excellent resistance against molten metal. Reheating furnaces are mainly lined with insulating monolithics and fiber modules. Scale dust, atmosphere impurities, and sometimes alkalis coming from the burners are attacking the lining, causing its aging. Progressively, ceramic fibers shrink, crack, and collapse. Thanks to its intrinsic stable properties, Norfoam® A enables to prevent this premature wear. Norfoam® products can be installed as covering layer (plate design) directly on the existing fiber insulation modules, which also involves a gain in installation time and process viability.

Fig. 12 Setters made of Norfoam®

The Norfoam® products can be used as well in petrochemical industry because of their high chemical inertness, high specific area and pore interconnection, making the product an excellent choice to be used in installations with catalytic reactions.

6 Conclusions

Ceramic insulating foams like Norfoam® are offering a serious alternative to fiber or high-grade insulating bricks with advanced properties. Thanks to a significant improvement of the foam properties and manufacturing process with largest volume, nowadays ceramic foam ceramics are able to satisfy the demand by offering an innovative and performing material meeting the latest HSE standards.

Despite its moderate insulating properties compared to RCFs, the ceramic foam has now demonstrated numerous high values benefits for the users in terms of cross contamination, ablation resistance, ageing, machinability and dimensional stability compared to fibers. As per their optimised insulating behaviour, low mass inertia, chemical inertness, high strength, low specific energy need and improved economical accessibility, the applications where ceramic foams are used to replace fiber or insulating bricks are constantly growing and drawing a very positive outlook of this innovative material for the future.

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91. Glastechnische Tagung der Deutschen Glastechnischen Gesellschaft (DGG)

29. – 31. Mai 2017 in Weimar

Weimarhalle

Wissenschaft trifft Technologie // Science meets Technology

The Annual Meeting of DGG 2017 will be held in Weimar. There will be sessions topically devoted to glass science and glass technology. The conference language is English. On request, oral presentations on technical topics may be alternatively presented in German. They will be accommodated in specific sessions run in German language. Posters are to be presented in English in any case. Beyond the oral lectures and poster presentations, interesting excursions to nearby industrial enterprises will be offered.

Individual sessions of the 91st Annual Meeting of DGG are composed by experts in the respective fields; they are devoted to the following topics:

Session S1: *Glass Ceramics and Photonics*
Chair: Christian Rüssel, OSIM Jena

Session S2: *Advanced Glasses*
Chair: Ralf Müller, BAM Berlin

Session S3: *Glass Formation and Relaxation*
Chair: Dominique de Ligny, Univ. Erlangen-Nürnberg

Session S4: *Glasses in Healthcare*
Chair: Aldo R. Boccaccini, Univ. Erlangen-Nürnberg
Delia S. Brauer, OSIM Jena

Session T1: *Glass Surfaces*
Chair: Edda Rädlein, TU Ilmenau

Session T2: *Hot Forming, Secondary Manufacturing, Quality Control*
Chair: Michael Kellner, Heye-International
Gesine Bergmann, HVG

Session T3: *Energy, Environment and Glass Furnaces*
Chair: Bernhard Fleischmann, HVG

Session T4: *New Developments in Glass Technology*
Chair: Heiko Hessenkemper, Bergakademie Freiberg

Session T5: *Laser Application on Glass*
Chair: Jens Bliedtner, Ernst-Abbe-Hochschule Jena
Thomas Schmidt, ifw – Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung Jena

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