New Silicon Nitride-Bonded Silicon Carbide Tile System for Waste-to-Energy Boilers – Implemented Optimisations in Installation, Process (Heat Transfer) and Service Life

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Materials and Corrosion

1. The development of a state-of-the-art silicon-nitride-bonded silicon carbide boiler tile system

In April 2014 Van der Hoeff Refractories (VDHR), a continuation of a Benelux-based refractory company, developed its own boiler tile system. Due to ongoing service contracts with our own customer base, the practical use of the *state-of-the-art* system was implemented immediately. From past experience, there have been concepts for refractory tube wall protection available in the market, but none of them fully comply with the requirements of a *state-of-the-art* concept:

- monolithic (Refractory castable or Refractory ramming mass),
- mortared ceramic- and silicon nitride-bonded SiC tile systems,
- rear-vented silicon nitride-bonded SiC boiler tile systems,
- back-filled silicon nitride-bonded SiC boiler tile systems.

The designs of all SiC boiler tile systems on the market are around 10-20 years old and the goal with their development was to replace the castable-, and/or refractory (SiC) mass linings used at that time, and to extend the service life. The service life of the boiler tile systems at the beginning, was approximately 12 months. Today however, a service life of 2 to 6 years is achieved depending on the position of the tiles in the boiler and chemical / physical conditions. The challenge was to combine the own 20 years of practical experience and the latest theoretical knowledge into a new, all-round optimised and more economical boiler protection tile concept. One focus has been on the end-to-end system design, e.g. that even semi-skilled installation personnel can install at a high-quality level. Here, the use of the system in the offshore developing markets is considered, where less experienced labourers are employed.

The new tile system family refers to the backfilled- and rear-vented concept. Depending on the process requirements, the different variants allow specific concepts with different thermal conductivities without having to replace the main components of the system and the assembly method. The system offers maximum end-to-end flexibility, so that the best application can be implemented in all situations.

The system can be used even in geometrically difficult areas such as corners, curved tube sections and on collectors (headers). In the past this could only be done with (SiC) castables and (SiC) ramming materials.

Figure 1: The system can be used even in geometrically difficult areas such as corners, curved tube sections and on collectors (headers); in the past this could only be done with (SiC) castables and (SiC) ramming materials

2. The concept, requirements and starting points

Starting points of the system

Requirements derived from practical experience:

- long, reliable and predictable service life in all boiler segments
  - high quality installation due to uncomplicated design; assembly by semi-skilled workers,

  - maximum installation speed, direct cost reduction and increased availability,
  - improved cost-efficiency of the complete equipment [2] i.e. minimalized Total Cost of Ownership (TCO).
- from experience this can be achieved through
  - best material quality and production, especially for the boiler tile system and for the anchors,
  - optimal constructional quality, limited material stress at high temperatures and flexibility in case of temperature changes.

2.1. Best quality of the materials used

The quality characteristics of the SiC tiles of a system are characterised by very pure (unfortunately expensive) SiC material [3], by a homogeneous tile pressing process and a controlled firing process. The most important requirements for the silicon nitride-bonded SiC tiles are: a high oxidation resistance (according to ASTM C863) and thus low irreversible linear change, high thermal conductivity and low porosity. Other parameters such as thermal shock resistance and cold crushing strength (CCS) provide information about the properties of the SiC tile in practice and whether the production meets the specified quality demands.

2.2. Maximum construction quality

The construction design took an uncompromising account of many years of experience in the inspections of boiler tile systems: Many failure mechanisms have been analysed over the years, with the concept of designing a *state-of-the-art* system.

Table 1: Avoiding the well-known shortcomings in the development of the new boiler tile system concept

Common shortcomings, experienced over the years include:	
defects	**construction, conceptual measures**
tiles bend vertically and break away from the anchor	shorter SiC tile, position anchor vertically away from the centre of the tile
vertical cracks in the tiles	reinforcement of the SiC tile and shorter, recessed anchors
cracks in the tiles in general	smaller tiles, homogeneous tile pressing and homogeneous firing process
anchor corrosion	shorter anchor, recessed, stronger, better cooled, without thread (smooth surface), anchor alloy
tiles expand to the maximum design allowance.	by means of a suitable SiC tile format, material quality and ensuring the joint width during installation with liner/spacer
horizontal expansion felt compressed by tile panel weight during installation; decreased and uncontrolled horizontal joint width	stable horizontal joint by use of liner-spacers

Figure 2: Stud welding of the anchors

Figure 3: Inserting the wedge into the vertical channel

2.3. Uncomplicated design

The circumstances under which refractory installers must work in boilers are often far from ideal. To keep the risk of installation errors as low as possible the assembly of the tile system is therefore *self-guiding*. Also, with the fact that different European boiler manufacturers have to carry out their projects in distant countries, sometimes with inexperienced local refractory bricklayers, an uncomplicated boiler tile system is a great advantage.

2.4. Maximum installation speed

WtE boiler operators require higher equipment availability and thus shorter maintenance lead times. The costs per non-productive hour amount to several thousands of Euros.

Figure 4: Back-filling of the liner/spacer stabilised SiC tile wall

Since the first installation of the new system in June 2014 in Wilrijk, Belgium, it has become clear that the installation time is shorter. In a relatively small boiler (10 tonnes of waste per hour), the customer has found a saving of approximately 40 % on installation time, when replacing 200 m^2 of SiC boiler tiles, compared to the previously built-in back-filled tile system. Since the introduction in June 2014, more than 5,000 m^2 of the new system has been installed. The assembly speed has been significantly higher than in the past, in all cases.

2.5. Improved overall cost-efficiency

Detailed analyses show that the appropriate refractory lining makes a significant contribution to cost-efficiency. [2]

In addition to the direct costs of refractory repairs (material and installation costs), also of crucial importance are:

- the long flexible maintenance cycles,
- the frequency and lead time of the revisions,
- the quality and condition of the refractory lining.

Modern refractory systems are characterised by the best (raw) material quality, low-stress construction and *installation quality by design*. These Refractory systems achieve a reliable and long service life, so they are not the bottleneck for planned revision work. In the past, boilers were sometimes taken out of service unduly and inspection intervals were shortened because the refractory had failed – these events are almost history since *state-of-the-art* refractory concepts have been installed.

In addition to a long service life, modern boiler tile systems are characterised by so-called best assembly quality and short assembly times, enforced *by design*. If boilers are repaired or revised to the standards of these modern boiler tile systems, considerably shorter installation lead times are achieved. This, combined with short heat-up curves of the low stress boiler tile system, allow a boiler to go into service a few days earlier than before which increases the annual availability and cost-efficiency. In other words: a significantly lower Total Cost of Ownership (TCO).

It makes strategic sense to invest in modern boiler refractory systems – an important aspect to increase cost-efficiency significantly, without additional effort and with lower risk.

3. Boiler tube protection tile system [1]

3.1. General characteristics

Unlike many other systems available on the market, the system is characterised by its consistently simple design. Both the tile system and the effect on the installation.

The image shows a cross section of the system installed on the membrane wall of a boiler.

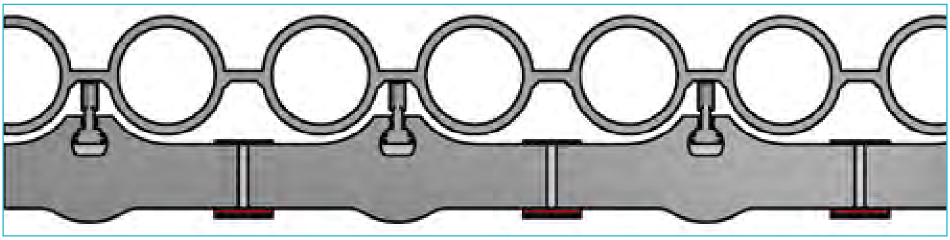

Figure 5: Horizontal cross section through SiC boiler tile system on the membrane wall

Features:

- The anchors are short, thus remain relatively cool and are protected by the tile.
- The relatively small tile and the central anchor position make it a flexible system, both during installation and later during operation.
- Due to the central anchor position and the fixed anchor length, the system follows any deviations in the membrane wall.
- An evenly divided anchor pattern of 40 to 60 anchors/m^2, depending on the tube pitch centre to centre.
- The red liner-spacer connect the tiles to each other, in combination with the wedges that fix the tile in the anchor channel, and ensures that all anchors support the tiles. This results in a perfectly smooth and stable wall, which is then back-filled with self-flowing SiC castable.

Figure 6: Boiler tile system mounted on the prism membrane wall

3.2. Silicon nitride-bonded silicon carbide tile

Due to the simple and robust shape of the tile, the shape of the central channel and the perfect matching anchor, the installation is easier and more rapid. The shape of the channel and the anchor provides low-stress contact between the tile and the anchor. Due to the continuous vertical channel in the tile, the height of the anchor is not critical and does not have to be precisely measured. Cut to size tiles can also be easily installed.

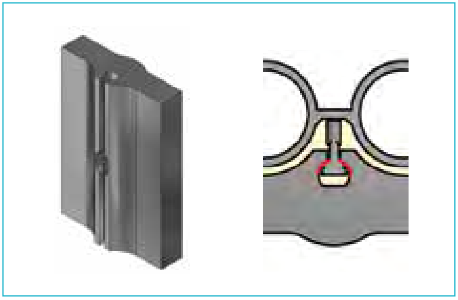

Figure 7: SiC tile

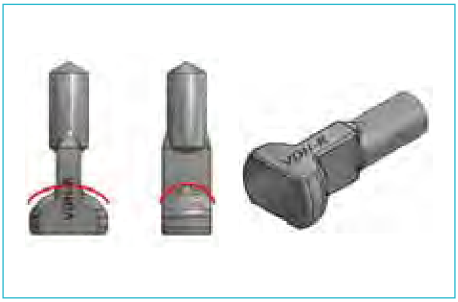

Figure 8: Anchor bolt

3.3. Anchor bolts

The anchors are cast in one piece from AISI 309 material with a maximum of 0.03 % carbon. Due to the simple form installation errors are avoided by incorrect setting. The anchor is welded to the membrane strip by means of *stud welding*. This welding process is semi-automatic provides a reliable welded joint.

In addition, the anchor is relatively short and robust. Unlike systems with, for example, a thread, the new system not only offers a much higher strength, but also a much smaller specific surface area, so that thermal and / or chemical influences on the anchor remain limited.

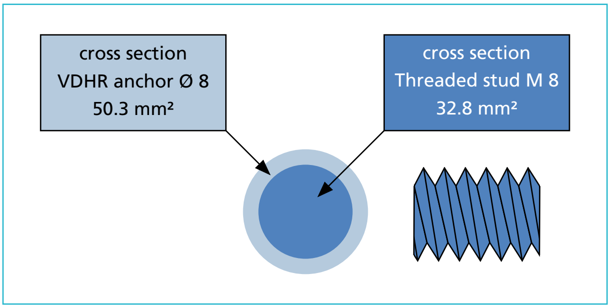

Figure 9:

Comparison cross sections through anchor Ø 8 and threaded stud M 8

Comparison of the cross sections

- 32.8 mm^2 M8 threaded stud,
- 50.3 mm^2 Ø8 VDHR anchor bolt.

The standard material quality is the proven AISI 309 and furthermore the anchor is also available in Inconel 625, for application on overlay welded membrane walls.

3.4. Liner-Spacer

The human factor during installation largely determines the final quality of a system. By making the system not only simpler but also making the installation self-guiding, the influence of this factor is kept to a minimum.

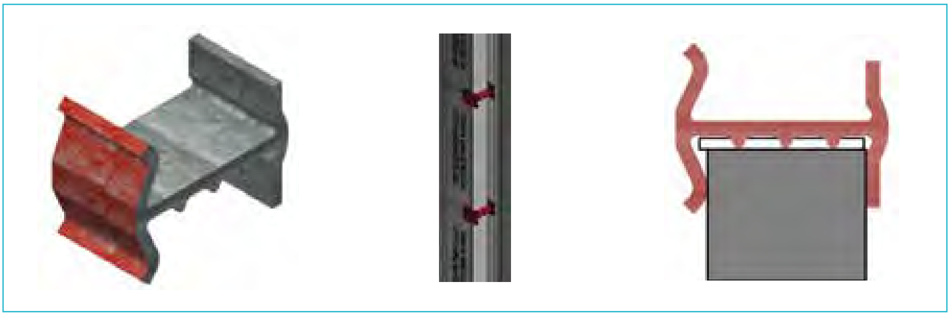

Figure 10: Liner-Spacer

Liner-Spacer has the following functions:

- ensure that the tiles surface is flat,
- keeps the expansion material between the tiles in place,
- determines the dimension (5 mm) of the horizontal expansion joint between the tiles.

The item only has a function during installation and consists of a bio-soluble fibre material and a resin binder. This binder melts / vaporizes during boiler start-up, while the fibre remains in the joint. Because it is a high temperature fibre material, similar to the expansion material present in the joints, no voids remain.

3.5. Refractory wedge (60 % SiC)

The VDH-R wedge has been developed to stabilise the tile wall after dry installation and before back-filling with the self-flowing SiC castable. The wedge consists of a 60 % SiC castable, so identical to the back-fill castable. The application is easy: slightly pull the tile forward, drop the wedge into the channel and everything is fixed. The fine-grained, self-flowing 60 % back-fill castable subsequently fills all open spaces between the membrane wall and tile system as the last assembly step.

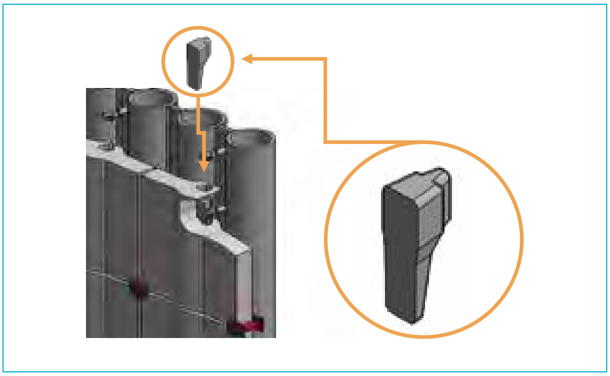

Figure 11: Principle wedge

4. Chemical/physical analysis of silicon nitride-bonded silicon carbide

4.1. Summary of test program by Flux Refractory BV

Silicon nitride bond SiC samples were analysed by the Deutsches Institut für Feuerfest und Keramik (D.I.F.K.) for: Steam oxidation resistance according to ASTM C 863, cold crushing strength, apparent density and apparent porosity. The crystalline structure and composition was examined using XRD-Analysis and Rietveld refinement by the Ceramic Research Centre (C.R.C.) of Tata Steel in IJmuiden (NL).

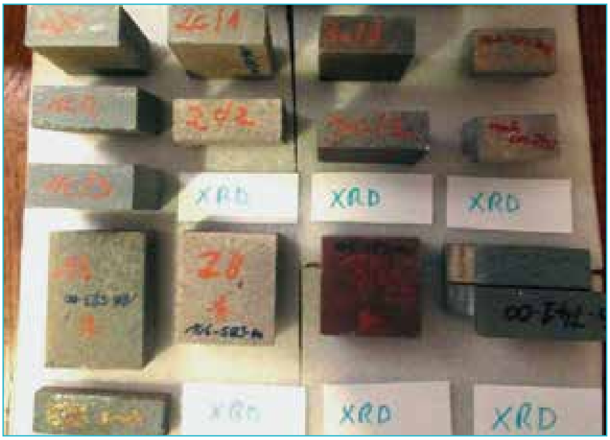

Figure 12:

Overview SiC test samples first Phase

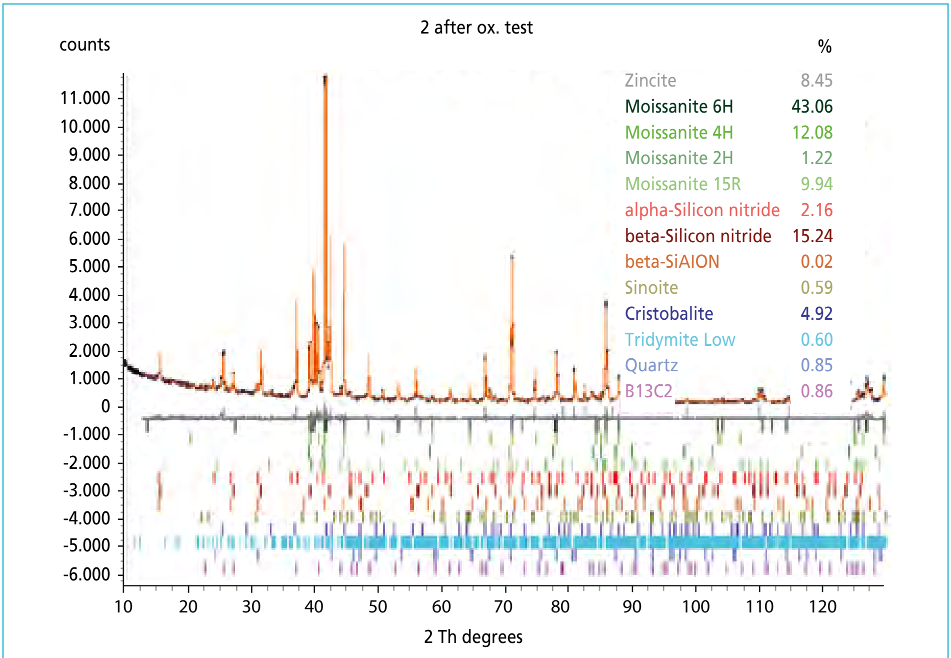

Figure 13: XRD / Rietveld analysis

Source: Flux Refractories BV

4.2. Selection of the best material and the best production process

The investigation provided reliable insights into the SiC grades available on the market and their varying impurities. Moreover, much has been learned (and still to be learned) regarding the ageing of SiC under the conditions to which the materials are exposed. In addition to the design improvements made to the tile system, it is necessary to produce the tiles with optimum qualified material. In addition to the four materials that we tested in our test, the table below contains two additional materials that were examined later. Actually, (European) suppliers nr. 2, 5 and 6 are approved and manufacture(d) the tiles.

Table 2: Analysis values of silicon nitride-bonded SiC samples

Average value	Number of specimens	Bulk density	Bulk density	Weight	Weight	Weight	Volume	Volume	Apparent Volume	Linear	Apparent porosity	Apparent porosity	Apparent W/V ration	True density	True density	True density
		At Start	After 500 hours	At Start	After 500 hours	Expansion	Apparent	Apparent	Expansion	Expansion	At Start	after 500 hours		Calculated	Calculated	Difference
						Δ Start / aft.500 hrs	At Start	After 500 hours	Δ Start / aft.500 hrs	Δ Start / aft.500 hrs				At start	After 500 hrs	Δ Start / aft.500 hrs
		kg/dm³	kg/dm³	g	g	%	cm³	cm³	%	%	vol.-%	vol.-%	Apparent W% / V%	kg/dm³	kg/dm³	%
1	4	2,551	2,593	552.47	577.62	4.53	217.31	223.76		0.95	19.5	11.83	1.6	3.17	2.94	-7.8
2	4	2,674	2,699	545.91	551.58	1.07	203.98	204.27	0.15	0.05	11.7	8.00	33.6	3.03	2.93	-3.3
3	4	2,705	2,716	493.22	506.34	2.68	182.51	186.65	2.26	0.75	12.4	8.80	1.3	3.09	2.98	-3.6
4	3	2,723	2,751	225.22	233.06	3.46	82.72	84.72	2.39	0.79	13.9	6.13	1.5	3.16	2.93	-7.9
5	3	2,578	2,662	194.73	202.59	4.21	75.55	76.24	0.92	0.31	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
6	9	2,700	2,736	207.68	210.76	1.52	76.88	77.01	0.18	0.06	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Samples 1, 2, and 3 First test run August / September 2014 by Flux refractories BV / DIFK GmbH, copy of DIFK test rapport available
Samples 4, second test run September / October 2014 by Flux refractories BV / DIFK GmbH, copy of DIFK test rapport available
Sample 5 Test results provided by Eu supplier, Nov. 2014, testing by DIFK GmbH, date unknown, copy of DIFK test rapport available
Sample 6 Test Results by DIFK GmbH, July 2015, provided by current supplier, copy of DIFK test rapport available

5. Conclusion and principle of system stability

Optimum heat transfer by system stability i.c. with best SiC quality

The system in combination with the best quality of nitride bond SiC material, guarantees optimum heat transfer. The system is stabile in all directions, before backfilling. This means that the backfill castable cures in peace, without disturbance of the continuing mounting of the tiles above the finished lining. The importance of this aspect may not be underestimated. In boiler tile systems, in which system stability before backfilling isn't realised, movement of tiles takes place during the curing of the backfill castable, thus corrupting the contact face between tile and castable. With other words, minor cracks will appear with major nestive influence on the heat transfer. The figures below shows the theory.

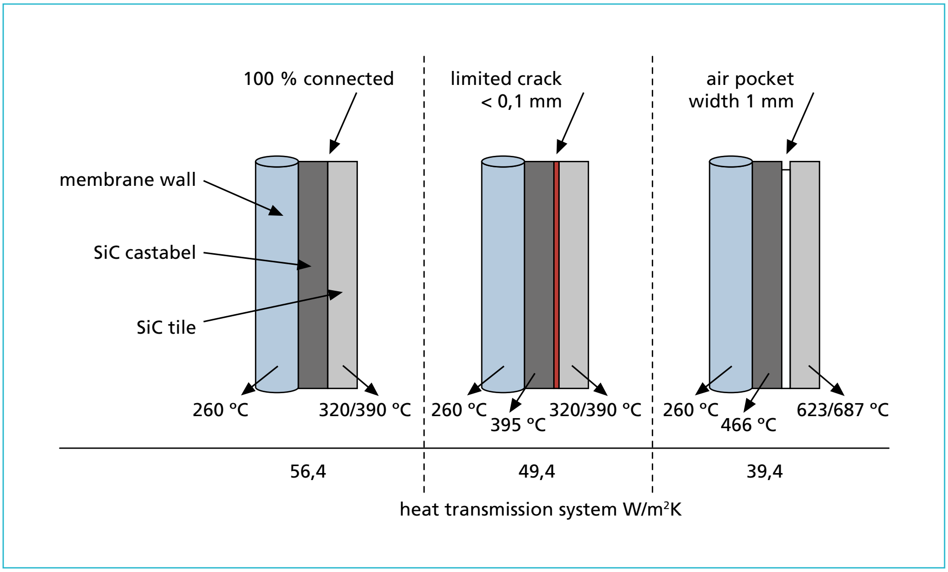

Figure 14: Effect of cracks between SiC tiles and castable

Source: Karl-Ulrich Martin

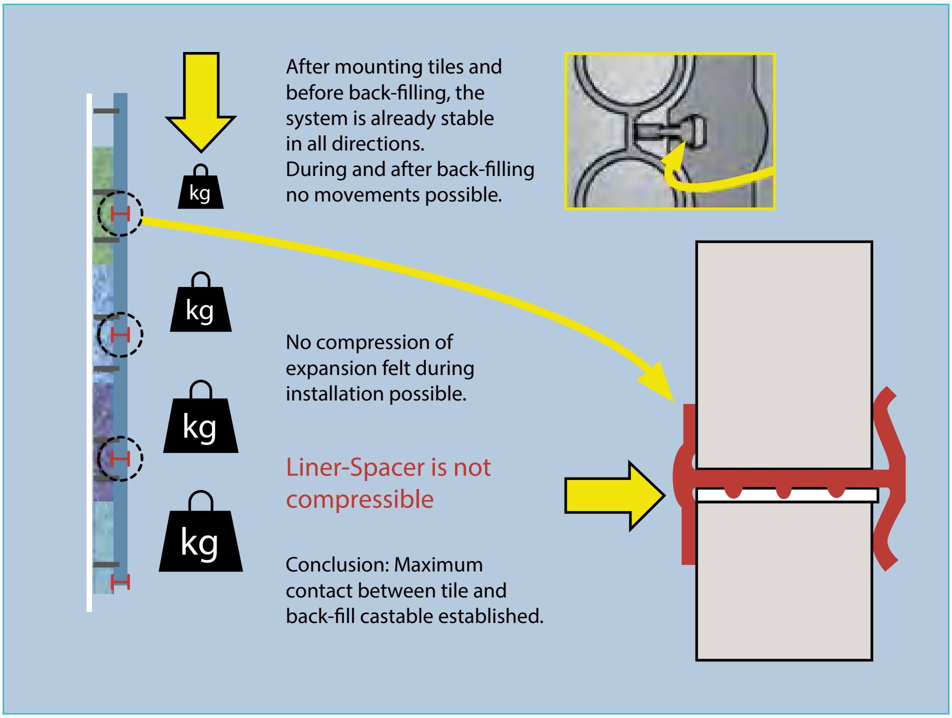

Figure 15: VDH-R system stability

6. Sources

[1] International patent application 'Refractory tube wall lining for an incinerator', PCT no. PCT/NL2015/000019. Entered regional / national phase December 2016 for: EP, US, CA, CN, EA, JP.

[2] Martin, K.-U.; Metschke, J.; VGB Conference Thermal Waste Utilization, Ceramic Membrane wall protection systems in Economic Comparison, May 05, 2006 Hamburg, Hotel Gastwerk.

[3] Van der Hoeff Refractories B.V; Public Presentations.[NL2015/000019. Entered regional / national phase December 2016 for: EP, US, CA, CN, EA, JP.

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