



(51) International Patent Classification:
H05B 3/28 (2006.01)

(21) International Application Number:
PCT/EP2024/065727

(22) International Filing Date:
07 June 2024 (07.06.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
23178475.2 09 June 2023 (09.06.2023) EP

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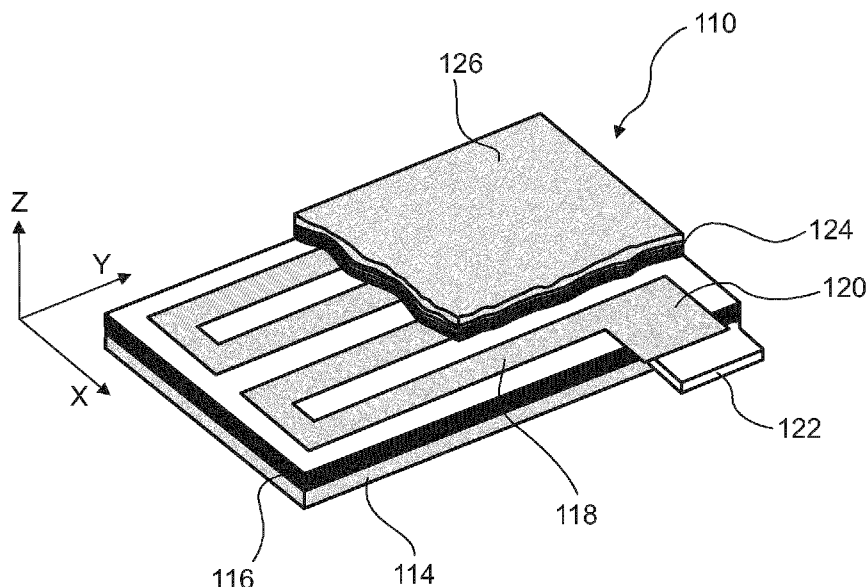
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) Title: A HEATING PANEL

FIG.1A



(57) Abstract: A heating panel (112) comprising at least one layered structure (128) is disclosed. The layered structure (128) comprises at least one heating conductor (118) embedded in a first supporting structure of Oxide Ceramic Matrix Composite (OCMC) (116). The heating panel (112) has a normalized shell thickness $S_{norm} = s/D_{eq}$ from 0.0001 to 0.01, with s being a thickness of the panel and $D_{eq} = 4A/U$ with A being a surface area of the heating panel and U being a perimeter of the surface area.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

A heating panel

Technical Field

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The invention relates to a heating panel, an apparatus for heating a feedstock comprising at least one heating panel and several uses. For example, the heating panel can be used for radiation heating, preferably radiation heating in an industrial furnace, more preferably radiation heating in a reactor furnace. However, other applications are possible.

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Background art

When transforming industrial furnace, e.g. of steam crackers, from fossil heating to electric heating, finding suitable heating elements for heating cracker coils is challenging. The problem is that the heating elements are usually installed as self-supporting elements in a furnace chamber. This may result in conflicting properties regarding mechanical resistance and thermal surface load of the heating elements. On the one hand, heating elements with a low specific surface area may be mechanically stable but tend to overheat. On the other hand, heating elements with a high specific surface area may release the heating power at a low overtemperature but are susceptible to distortion. Moreover, replacement of the heating source with an otherwise unchanged reactor design may not result in an economically optimal solution. A significant part of the electric power supply would be delivered as inferior sensitive heat with the product stream. For example, DE102016118137, DE102016113815, WO2018077612, DE102017112611, GB2218310 describe heating elements.

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EP 3 835 639 A1 discloses to a gas-tight multilayer composite tube having a heat transfer coefficient of $> 500 \text{ W/m}^2/\text{K}$ comprising at least two layers, an inner layer consists of a nonporous monolithic oxide ceramic, which is enclosed by an outer layer of oxide fiber composite ceramic, wherein this outer layer has an open porosity of $5\% < \varepsilon < 50\%$, preferably $10\% < \varepsilon < 30\%$, wherein an electrically conductive system is integrated in the outer annular space of the multilayer composite tube, the boundaries of which are defined by the outer surface of the inner layer and by the inner surface of the outer layer. Moreover, it relates to the use of the multilayer composite tube as a reaction tube for endothermic reactions, lances or rotary tubes. The closed circumferential surface of cylindrical shape is considered a necessary feature to ensure the stability of the multilayer wall structure.

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US 2019/208579 A1 describes infrared panel radiators including a carrier with a heating surface, and a printed conductor made of an electrically conductive resistor material that generates heat when current flows through it.

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US 6,507,006 B1 describes a ceramic substrate. The ceramic substrate is a ceramic substrate comprising a conductor layer formed therein, wherein at a section of the edge of the conductor layer is in a peaked shape.

US 2010/147828 A1 describes a linear heater which includes a linear supporter, a heating element and at least two electrodes. The heating element is located on the linear supporter and includes a carbon nanotube composite structure. The carbon nanotube composite structure includes a matrix and at least one carbon nanotube film. The at least one carbon nanotube film includes a plurality of carbon nanotubes entangled with each other. The at least two electrodes are electrically connected to the heating element.

Problem to be solved

It is therefore desirable to provide a heating panel and an apparatus which at least partially address above-mentioned technical challenges of known methods and devices. Specifically, a heating panel shall be provided which is suitable for electrical industrial furnaces such as in industrial reactors for cracking.

Summary

This problem is addressed by a heating panel, an apparatus and several uses with the features of the independent claims. Advantageous embodiments which might be realized in an isolated fashion or in any arbitrary combinations are listed in the dependent claims as well as throughout the specification.

As used herein, the terms "have", "comprise" or "include" or any arbitrary grammatical variations thereof are used in a non-exclusive way. Thus, these terms may both refer to a situation in which, besides the feature introduced by these terms, no further features are present in the entity described in this context and to a situation in which one or more further features are present. As an example, the expressions "A has B", "A comprises B" and "A includes B" may both refer to a situation in which, besides B, no other element is present in A (i.e. a situation in which A solely and exclusively consists of B) and to a situation in which, besides B, one or more further elements are present in entity A, such as element C, elements C and D or even further elements.

Further, it shall be noted that the terms "at least one", "one or more" or similar expressions indicating that a feature or element may be present once or more than once typically are used only once when introducing the respective feature or element. In most cases, when referring to the respective feature or element, the expressions "at least one" or "one or more" are not repeated, notwithstanding the fact that the respective feature or element may be present once or more than once.

Further, as used herein, the terms "preferably", "more preferably", "particularly", "more particularly", "specifically", "more specifically" or similar terms are used in conjunction with optional features, without restricting alternative possibilities. Thus, features introduced by these terms are optional features and are not intended to restrict the scope of the claims in any way. The inven-

tion may, as the skilled person will recognize, be performed by using alternative features. Similarly, features introduced by "in an embodiment of the invention" or similar expressions are intended to be optional features, without any restriction regarding alternative embodiments of the invention, without any restrictions regarding the scope of the invention and without any restriction regarding the possibility of combining the features introduced in such way with other optional or non-optional features of the invention.

In a first aspect of the present invention, a heating panel comprising at least one layered structure is disclosed. The layered structure comprises at least one heating conductor embedded in a first supporting structure of Oxide Ceramic Matrix Composite (OCMC). The heating panel has a normalized shell thickness $S_{norm} = \frac{s}{D_{eq}}$ from 0.0001 to 0.1, with s being a thickness of the panel and $D_{eq} = 4 \frac{A}{U}$ with A being a surface area of the heating panel and U being a perimeter of the surface area.

The term "heating" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to at least one process for maintaining and/or changing a temperature of at least one element, e.g. a feedstock in a pipeline. For example, the heating may comprise heating a feedstock to a temperature range from 200°C to 1700°C, preferably from 300 °C to 1400 °C, more preferably from 400 °C to 875 °C. The temperature range may be dependent on an application. For example, the heating may ensure a constant temperature. For example, the heating may comprise supplying of an endothermic reaction at constant temperature.

The term "panel" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to a rigid module having a flat extension, e.g. a sheet and/or shell like element. The term "panel" further may refer to a geometrical property of an element.

The term "heating panel" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to a panel configured for providing at least one heating function.

The heating panel may have a geometry selected from the group consisting of: a planar geometry, an arched geometry, a regular or irregular geometry. In particular, a shape of the heating panel may be adjusted to a contour of a heating section. For example, the first supporting structure may be generated by laminating, thereby allowing to adjust the shape of the heating panel to the contour of the heating section.

The heating panel may have a surface area A. The surface area may refer to the total area that the surface of the object occupies. The surface of the heating panel may be planar. However, other embodiments such as curved, arched and/or shell-formed surfaces may be possible.

Techniques for determining the surface area A are known to the skilled person. The heating

5 panel may have a thickness s. The thickness may be defined as extension along a surface normal. The thickness may be defined as the smallest of three descriptive measurements: height, width and length.

The heating panel may be thin-walled. The term "thin-walled" as used herein is a broad term
10 and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to the fact that the thickness of the heating panel is significantly smaller compared to the further dimensions of the heating panel. For example, a ratio of the thickness to an extension along the other dimension may be 1/10. The thickness of the heating panel may be from
15 0.5 mm to 10 mm.

The heating panel has a normalized shell thickness $S_{norm} = \frac{s}{D_{eq}}$ from 0.0001 to 0.1, with s being a thickness of the panel and $D_{eq} = 4 \frac{A}{U}$ with A being the surface area of the heating panel and U being the perimeter of the surface area. Preferably, the normalized shell thickness of the heat-
20 ing panel is from 0.0005 to 0.03. The heating panel may be designed as cylinder segment of a circumference of a cylinder, e.g. a half shell.

The heating panel may have an area of 0.01 m² to 50 m², preferably from 0.05 m² to 10 m², more preferably from 0.1 m² to 5 m². The heating panel may have a length of 0.1 m to 50 m,
25 preferably from 0.5 m to 30 m, more preferably from 1 m to 20 m. The heating panel may have a width of 0.05 m to 2 m, preferably from 0.1 to 2 m, more preferably from 0.1 to 1 m. The heating panel may have a bending of 0 1/m to 3 1/m, preferably from 0 1/m to 2 1/m, more preferably from 0 1/m to 1 1/m. The heating panel may have a thickness of 0.5 mm to 10 mm, preferably from 1.5 mm to 7.5 mm, more preferably from 2 mm to 5 mm. However, also other dimensions may be feasible.
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The term "layered structure" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to the fact that the heat-
35 ing element comprises a plurality of layers and/or elements.

The terms "first", "second" and other terms of a similar nature are used as nomenclature, without hereby order or ranking. Also, several "first" or "second" properties and/or elements may be provided.

The layered structure comprises at least one heating conductor embedded in a first supporting structure of OCMC.

Previous attempts to integrate electrically conductive structures in a flat ceramic plate have been unsuccessful as it caused cracks in the plate, in particular due to the brittleness of the used material. However, the present invention allows for using OCMCs (including all the benefits that go with it) by the proposed layered structure.

The term “supporting structure” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an element of the layered structure configured for providing at least one supporting function. For example, the supporting function may be providing stiffness and/or strength e.g. against internal and/or external loads. The supporting structure may provide the dimensional stability of the heating panel.

As outlined above, the first supporting structure is of Oxide Ceramic Matrix Composite (OCMC). The term “composite material” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary material being produced from two or more constituent materials. These constituent materials may have notably dissimilar chemical or physical properties and may be merged to create a material with properties unlike the individual materials. Within the composite material, the individual materials may remain separate and distinct. Specifically, the composite material may be a fiber-reinforced composite material. The term “fiber-reinforced composite material (FRC)” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary material generally comprising at least two main components: reinforcing fibers and an embedding matrix which may serve as a filler and/or adhesive between the fibers. Mutual interactions between the two components may give overall material higher-grade properties than either of the two components involved alone. The fiber-reinforced composite (FRC) may specifically comprise the fibers as a discontinuous or dispersed phase, the matrix as a continuous phase and an interphase region, which may also be referred to as interface.

The term “Ceramic Matrix Composite (CMC)” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary composite material, specifically to an arbitrary fiber-reinforced composite material, comprising a plurality of ceramic fibers embedded in a ceramic matrix. Thereby, carbon and carbon fibers may also be regarded as a ceramic material. The term “Oxide Ceramic Matrix Composite (OCMC)” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized

meaning. The term specifically may refer, without limitation, to an arbitrary ceramic matrix composite comprising an oxide ceramic matrix reinforced by oxide ceramic reinforcing fibers. The term "OCMC" may refer to pure OCMC structures and to hybrid OCMC structures comprising in addition to the OCMC at least one further material such as metallic fibers. Specifically, OCMCs are fiber reinforced composite materials comprising oxide fibers embedded in a porous matrix of oxide ceramics. Advantages of such OCMCs can be ensuring high temperature resistance up to 1300 °C or above, high thermal shock resistance and quasi-ductile deformation and fracture behavior. An open porosity ϵ of fiber composite ceramics can usually take on values between 5% and 50%. A fracture toughness of OCMC can reach values of $K_{IC} \cong 10 - 50 \text{ MPa}\cdot\text{m}^{0.5}$. As a result of the porous structure, fiber composite ceramics may have a lower density, a lower modulus of elasticity and a lower thermal conductivity coefficient compared to monolithic ceramics with the same chemical composition. The following table gives a list of the relevant standards for the determination of these parameters; in particular a list of relevant norms for the determination of structural, mechanical and thermophysical parameters for monolithic ceramics and for OCMC.

Parameter	Monolithic ceramics	OCMC
Density, open porosity	DIN EN 623-2	DIN V ENV 1389
Modulus of elasticity	DIN V ENV 843-2	DIN EN 658-1
Fracture toughness ¹	DIN EN ISO 15732	Single-edge-notch-bend ²
Thermal diffusivity coefficient	DIN EN 821-2	DIN V ENV 1159-2
Specific heat capacity	DIN EN 821-3	DIN V ENV 1159-3
1: The fracture toughness of metallic materials is determined according to DIN EN ISO 12737.		
2: M. Kuntz. Risswiderstand keramischer Faserverbundwerkstoffe. Dissertation Universität Karlsruhe, p. 52-58, Shaker Verlag, 1996.		

The thermal conductivity coefficient is defined by the following relationship: thermal conductivity coefficient = density x (specific heat capacity) x thermal diffusivity coefficient.

As an example, the following table compares between the properties of monolithic ceramics and OCMC based on aluminum oxide.

Parameter	Monolithic ceramics e.g. Degussit® AL23	OCMC e.g. WHIPOX® N610/45
open porosity in %	0	26
Density in (g/cm ³)	3.8	2.9
Modulus of elasticity in <i>GPa</i>	380	110
Thermal conductivity coefficient in W/(m*K)	30 (at 100°C) 5.5 (at 1000°C)	5.7 (at 200°C) 2.7 (at 1000°C)

For example, the OCMC may be prepared by the following manufacturing procedure: A fiber fabric in the form of a textile or a fiber bundle such as a rovings may be infiltrated with a slurry.

The infiltration may be carried out by dipping or knife coating. Several layers may be laminated over a suitable mold until a desired wall thickness is achieved. Drying may be carried out in a temperature range of 40 °C to 150 °C, preferably from 60 °C to 100 °C. In a subsequent step, the OCMC layer may be fired. Firing may take place in a temperature range of 1100 °C to 1300 °C, preferably in a temperature range of 1150 °C to 1250 °C.

Specifically, components made of OCMs may be manufactured using a manufacturing process as described, for example, in DE102016007652A1, comprising the following steps: The textile framework is impregnated with a slurry and placed on a mold or laminated. A slurry may be understood to be the pulpy to pasty mixture of water and mineral powder, which is used as a raw mass for the production of ceramic products. For example, the powder contains metal oxides, carbides, nitrides. Preferably, the powder contains aluminum oxide, zirconia, mullite or zirconia reinforced aluminum oxide. Subsequently, the component is dried at temperatures of 40 °C to 150 °C, preferably from 60 °C to 100 °C. This can allow giving the component sufficient stability that it is self-supporting and can be removed from the mold. Finally, the component may be fired in a high-temperature furnace at temperatures of 1100°C to 1300°C, preferably in a temperature range of 1150 °C to 1250 °C. The finished component may comprise an intimate composite of the textile framework and a sintered, porous ceramic matrix.

However, also other manufacturing processes may be possible.

As outlined above, the OCMC may have a matrix, specifically an oxide ceramic matrix. The term “matrix” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary constituent of a composite material. Specifically, the matrix may refer to or may comprise at least one material in which other components are embedded. The matrix may specifically serve the following functions. The matrix may be configured for binding a fiber reinforcement. Further, the matrix may be configured for providing a composite component its shape and may direct its surface quality.

The matrix may specifically comprise at least one of: a binary oxide (M_xO_z); a mixed oxide such as $M1_xM2_yO_z$ and/or $M1_xM2_yM3_wO_z$; a complex matrix comprising a plurality of ceramic particles and/or of metallic particles. Specifically, the OCMC may have a matrix composition selected from the group consisting of: $Si_xM_yO_z$, $Si_xM1_yM2_wO_z$, $Si_xB_yN_zC_w$, AlN , M_xO_y and mixtures of oxides ($M1_xO_y/M2_wO_z$). For example, the OCMC may have a matrix composition comprising a mixture of oxides such as 85% Al_2O_3 and 15% ZrO_2 (e.g. a matrix available under FW12 from WPS). However, also other kinds of materials may be possible.

Thereby, O may refer to the chemical element oxygen. B may refer to the chemical element boron (B). N may refer to the chemical element nitrogen (N) and C may refer to the chemical element carbon (C).

M may specifically be an element selected from the group consisting of: aluminum (Al), zirconium (Zr), silicon (Si), calcium (Ca), magnesium (Mg), beryllium (Be), yttrium (Y), lanthanum (La), iron (Fe), nickel (Ni), chromium (Cr), tungsten (W), hafnium (Hf), strontium (Sr). Preferably, M may be an element selected from the group consisting of: aluminum (Al), zirconium (Zr), silicon (Si), strontium (Sr), lanthanum (La), yttrium (Y). M1 may specifically be an element selected from the group consisting of: aluminum (Al), zirconium (Zr), yttrium (Y). Preferably, M1 may be aluminum (Al). M2 may specifically be an element selected from the group consisting of: zirconium (Zr), silicon (Si). Preferably, M2 may silicon (Si). M3 may specifically be cobalt (Co). x , y and w may each independently be between 1 and 10, preferably between 1 and 7 and most preferably between 1 and 5. z may specifically be between 1 and 30, preferably between 1 and 20 and most preferably between 1 and 10.

The metallic particles may specifically be made of at least one material selected from the group consisting of: an iron-based alloy, a nickel-based alloy, a platinum group metal (PGM) or a refractory metal. The metallic particles may specifically be made of at least one ferritic iron-chromium-aluminum alloy (FeCrAl alloy) or one of at least one material having a material number according to DIN 17007-2:1961-09: $n_1.m_1m_2m_3m_4$. n_1 may specifically be a digit from the group 1,2,3 and preferably a digit from the group 1 and 2. m_1 may specifically be a digit from the group 0, 1, 3, 4, 8, preferably a digit from the group 3 and 4 and particularly preferably the digit 4. m_2 may specifically be a digit from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, preferably a digit from the group 5, 6, 7, 8, 9 and particularly preferably a digit from the group 7, 8, 9. m_3 and m_4 preferably each independently may stand for one of the digits from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. FeCrAl alloys comprise for example products distributed under the trade name Kanthal® AF, Kanthal® A-1, Kanthal® D. PGM comprise the elements platinum, palladium, iridium, rhodium, osmium, ruthenium and alloys thereof. Refractory metals comprise the elements titanium, zirconium, hafnium, niobium, molybdenum, tantalum, tungsten, rhenium and alloys thereof.

Specifically, the matrix may be made of FW12 from Walter E.C. Pritzkow Special Ceramics (85% Al_2O_3 and 15% 3YSZ).

The first supporting structure of OCMC, specifically the matrix of the OCMC, may have a porosity from 10 % to 60 %, preferably from 20 % to 50 %, more preferably from 20 % to 40%. A pore size of the first supporting structure of OCMC, specifically the matrix of the OCMC, may specifically be between 0.001 μm and 100 μm , preferably between 0.01 μm and 10 μm and most preferably between 0.05 μm and 0.5 μm . However, also other embodiments may be possible.

As outlined above, the OCMC may have a plurality of fibers, specifically a plurality of oxide ceramic reinforcing fibers. The term "fiber" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary element having a length and a width, wherein the length of the element exceeds the width of the element such as at least by a factor of 5, preferably at least by a factor of 10 and most preferably at least by a factor of 20. The fiber may specifically be an artificial fiber. The artificial

fiber may be a fiber whose chemical composition, structure, and/or properties may be significantly modified during a manufacturing process. Artificial may refer to regenerated fibers and synthetic fibers.

- 5 The oxide ceramic reinforcing fibers may comprise at least one material selected from the group consisting of: a binary oxide (M_xO_z), a mixed oxide ($M1_xM2_yO_z$ or $M1_xM2_yM3_wO_z$), a metal (M), a metal carbide (M_xC_y). Specifically, OCMC may have oxide ceramic reinforcing fibers comprising at least one material selected from the group consisting of: mullite, Al_2O_3 , a combination of mullite and Al_2O_3 . However, also other kinds of materials may be possible.

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Thereby, O may refer to the chemical element oxygen (O) and C may refer to the chemical element carbon (C).

- 15 M may specifically be an element selected from the group consisting of: aluminum (Al), zirconium (Zr), silicon (Si), calcium (Ca), magnesium (Mg), beryllium (Be), yttrium (Y), lanthanum (La), iron (Fe), nickel (Ni), chromium (Cr), tungsten (W), hafnium (Hf), strontium (Sr). Preferably, M may be selected from the group consisting of: aluminum (Al), silicon (Si), strontium (Sr), zirconium (Zr), lanthanum (La), yttrium (Y). M1 may specifically be an element selected from the group consisting of: aluminum (Al), zirconium (Zr), yttrium (Y). Preferably, M1 may be aluminum (Al). M2 specifically be an element selected from the group consisting of: silicon (Si), zirconium (Zr). Preferably, M2 may be silicon (Si). M3 may specifically be cobalt (Co). x , y and w may each independently be between 1 and 10, preferably between 1 and 7 and most preferably between 1 and 5. z may specifically be between 1 and 30, preferably between 1 and 20 and most preferably between 1 and 10.

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- Metallic fibers may specifically be made of at least one material selected from the group consisting of: an iron-based alloy, a nickel-based alloy, a platinum group metal (PGM) or a refractory metal. Metallic fibers may specifically be made of at least one ferritic iron-chromium-aluminum alloy (FeCrAl alloy) or one alloy having a material number according to DIN 17007-2:1961-09: n1.m1m2m3m4. n1 may specifically be a digit from the group 1,2,3 and preferably a digit from the group 1 and 2. m1 may specifically be a digit from the group 0, 1, 3, 4, 8, preferably a digit from the group 3 and 4 and particularly preferably the digit 4. m2 may specifically be a digit from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, preferably a digit from the group 5, 6, 7, 8, 9 and particularly preferably a digit from the group 7, 8, 9. m3 and m4 preferably each independently may stand for one of the digits from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. FeCrAl alloys comprise for example products distributed under the trade name Kanthal® AF, Kanthal® A-1, Kanthal® D. PGM comprise the elements platinum, palladium, iridium, rhodium, osmium, ruthenium and alloys thereof. Refractory metals comprise the elements titanium, zirconium, hafnium, niobium, molybdenum, tantalum, tungsten, rhenium and alloys thereof.

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The OCMC may have a plurality of the oxide ceramic reinforcing fibers which may form a fiber fabric. The term "fiber fabric" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or

customized meaning. The term specifically may refer, without limitation, to a manufacturing of the fibers. The fiber fabric may be manufactured in a sheet, a mat, specifically a continuous mat, or as continuous filaments. The fiber fabric may be manufactured from at least one technique selected from the group consisting of: weaving, knitting, braiding and stitching. The fibers may be manufactured in two-dimensional or three-dimensional orientations. In the two-dimensional orientation the fibers may be essentially only aligned along a plane in x-direction, and in y-direction of the material. In the three-dimensional orientation fibers may be incorporated in the x-direction, y-direction and z-direction. The fiber fabric may also be referred to as fiber pre-form, fiber backbone, fiber scaffold or fiber framework.

The first supporting structure, specifically the plurality of the oxide ceramic reinforcing fibers, more specifically the fiber fabric, may have fabric, a mesh, a woven or a knitted structure. However, also other embodiments may be feasible.

The fiber fabric may specifically be woven in a weave pattern selected from the group consisting of: unidirectional, plain weave, twill K1/2, twill K2/2, twill K1/3, twill 4/4, atlas A1/4, atlas A1/7. Preferred weave patterns may be twill 2/2, twill 4/4, atlas 1/4, atlas 1/7, and specifically twill 4/4, atlas 1/4 and atlas 1/7. The fiber fabric may specifically be laminated at an angle of 0/90° or at an angle of 45°. However, also other embodiments may be feasible.

The fiber fabric may be a homogeneous fiber fabric or a hybrid fiber fabric. Specifically, the hybrid fiber fabric may also be part of a functional layer. The homogeneous fiber fabric may comprise exclusively one kind of fibers. The hybrid fiber fabric may comprise at least two different kinds of fibers. One kind of fibers of the hybrid fiber fabric may refer to fibers being electrically conductive. The fiber fabric may specifically comprise electrically conductive fibers as warp and/or weft threads. Preferably, the fiber fabric may comprise electrically conductive fibers as weft threads. The fibers being electrically conductive may comprise at least one of metals, carbon and silicon carbide, preferably at least one of metal and carbon and most preferably metal. The metallic fibers may be made of at least one material selected from the group consisting of: an iron-based alloy, a nickel-based alloy, a platinum group metal (PGM) or a refractory metal. The metallic fibers may specifically be made of at least one ferritic iron-chromium-aluminum alloy (FeCrAl alloy) or one alloy having a material number according to DIN 17007-2:1961-09: n1.m1m2m3m4. n1 may specifically be a digit from the group 1,2,3 and preferably a digit from the group 1 and 2. m1 may specifically be a digit from the group 0, 1, 3, 4, 8, preferably a digit from the group 3 and 4 and particularly preferably the digit 4. m2 may specifically be a digit from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, preferably a digit from the group 5, 6, 7, 8, 9 and particularly preferably a digit from the group 7, 8, 9. m3 and m4 preferably each independently may stand for one of the digits from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. FeCrAl alloys comprise for example products distributed under the trade name Kanthal® AF, Kanthal® A-1, Kanthal® D. PGM comprise the elements platinum, palladium, iridium, rhodium, osmium, ruthenium and alloys thereof. Refractory metals comprise the elements titanium, zirconium, hafnium, niobium, molybdenum, tantalum, tungsten, rhenium and alloys thereof.

The oxide ceramic reinforcing fibers may have a fiber diameter from 1 μm to 50 μm , preferably from 3 μm to 30 μm and most preferably from 5 μm to 20 μm . However, also other dimensions may be possible.

5 A plurality of single oxide ceramic reinforcing fibers, which may also be referred to as filaments, may be bundled to a strand, wire or yarn. Thereby, the plurality of single oxide ceramic reinforcing fibers may essentially extend in one direction. Specifically, the filaments may be twisted into a single yarn strand. One yarn strand may comprise 100 to 20000 filaments, preferably 200 to 10000 filaments. A yarn thickness according to ISO1144 may specifically be in the range of 50
10 to 2500 Tex, preferably in the range of 100 to 1500 Tex, most preferably in the range of 150 to 1000 Tex. A yarn may specifically be made of 200 to 10000 filaments, preferably of 300 to 3000 filaments, and most preferably of 300 to 2000 filaments. A fiber volume content may specifically be from 5% to 75%, preferably from 10% to 60% and most preferably from 20% to 50%. A diameter of the filaments may be from 1 μm to 50 μm , preferably from 3 μm to 30 μm , more preferably from 5 μm to 20 μm .
15

In an exemplary embodiment, a fiber fabric may comprise six superimposed fabric sheets wound in 0/90° orientation, e.g. of type DF-11 from 3M (St. Paul, MN, U.S.A.) which may be impregnated with slurry forming the matrix of the OCMC structure after firing. The slurry may com-
20 prise a mixture of 85% Al_2O_3 and 15% ZrO_2 . The slurry may comprise additional components.

The term “heating conductor” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to a heating element
25 configured for converting electrical energy into heat, in particular through the process of Joule heating. For example, the heating conductor comprises at least one metallic material or at least one conductive ceramic. For example, the heating conductor may be a resistance wire, e.g. a metallic resistance wire. For example, the heating conductor may comprise at least one electrically conductive material, such as at least one ceramic material. Metallic heating conductors
30 may specifically be made of at least one material selected from the group consisting of: an iron-based alloy, a nickel-based alloy, a platinum group metal (PGM) or a refractory metal. Metallic heating conductors may specifically be made of at least one ferritic iron-chromium-aluminum alloy (FeCrAl alloy) or one alloy having a material number according to DIN 17007-2:1961-09:
35 $n_1.m_1m_2m_3m_4$. n_1 may specifically be a digit from the group 1,2,3 and preferably a digit from the group 1 and 2. m_1 may specifically be a digit from the group 0, 1, 3, 4, 8, preferably a digit from the group 3 and 4 and particularly preferably the digit 4. m_2 may specifically be a digit from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, preferably a digit from the group 5, 6, 7, 8, 9 and particularly preferably a digit from the group 7, 8, 9. m_3 and m_4 preferably each independently may stand for one of the digits from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. FeCrAl alloys comprise for example
40 products distributed under the trade name Kanthal® AF, Kanthal® A-1, Kanthal® D. PGM comprise the elements platinum, palladium, iridium, rhodium, osmium, ruthenium and alloys thereof. Refractory metals comprise the elements titanium, zirconium, hafnium, niobium, molybdenum, tantalum, tungsten, rhenium and alloys thereof.

Ceramic heating conductor materials may be made of carbon (graphite or carbon fibers); carbides, e.g. silicon carbide (SiC) or zirconium carbide (ZrC); nitrides, e.g. silicon nitride (Si₃N₄); silicides, e.g. molybdenum disilicide (MoSi₂); binary oxides, e.g. Yttria Stabilized Zirconia (YSZ),
5 Magnesia Stabilized Zirconia (MSZ), titanium oxides (TiO); ternary oxides, e.g. Perovskite, ferrites. Also other materials may be feasible.

The heating conductor may comprise an elliptic, circular, or prismatic cross section. The heating conductor may comprise a rectangular, a circular, a snail-shaped, or a meandering structure in
10 a top view. For example, the heating conductor may be a wire, a ribbon, straight or coiled. The heating conductor may comprise a tape. However, also other embodiments may be feasible.

The heating conductor may exemplarily have a cross-section of 0.05 mm² to 1000 mm², preferably from 0.1 mm² to 100 mm², more preferably from 0.2 mm² to 100 mm². The heating conductor
15 may exemplarily have a width to thickness ratio (cross-section) of 5 to 10000, preferably from 10 to 500, more preferably from 20 to 200. The heating conductor may exemplarily have a thickness of 0.1 mm to 1 mm, preferably from 0.03 mm to 0.5 mm, more preferably from 0.05 mm to 0.3 mm. The heating conductor may exemplarily have a width of 1 mm to 500 mm, preferably
20 from 2 mm to 200 mm, more preferably from 5 mm to 100 mm. The heating conductor may exemplarily have a length of 1 m to 5000 m, preferably from 5 m to 1000 m, more preferably from 10 m to 500 m. The heating conductor may exemplarily have a specific surface (perimeter / cross section) of 1000 1/m to 200000 1/m, preferably from 2000 1/m to 100000 1/m, more preferably from 3000 1/m to 50000 1/m. The heating conductor may exemplarily have a gap width
25 between the traces of 1 mm to 20 mm, preferably from 2 mm to 10 mm, more preferably from 3 mm to 5 mm. However, also other dimensions may be feasible.

The heating conductor may exemplarily have an Ohmic resistance of 10 Ohm to 10000 Ohm, preferably from 20 Ohm to 5000 Ohm, more preferably from 50 Ohm to 1000 Ohm.

30 The term “embedded in” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to one or more of integral to, fixed on and/or within, or enclosed by. The layered structure may comprise a plurality of heating conductors embedded in the first supporting structure.

35 The heating conductor and the first supporting structure may be connected by one or more of at least one force-fit connection, at least one form-fit connection, or at least one material closure. For example, the heating conductor may be a shaped piece embedded in the first supporting structure of OCMC.

40 Specifically, the heating conductor may be manufactured by applying a material or a starting material of the heating conductor to a surface of the first supporting structure. The heating con-

ductor may exemplarily be plated by one or more of molding, printing or coating on the first supporting structure. Further, the heating conductor may exemplarily be plated by one or more of flame spraying, plasma spraying. Further, specifically, the heating conductor may be manufactured during the manufacturing process of the heating panel such as by laminating. However, also other methods may be feasible.

In a further embodiment, a tape of electrically conductive material is embedded between the first and second support structure. This tape may preferably consist of fiber strands of electrically conductive ceramic fibers, for example carbon or silicon carbide fibers. These fibers can be twisted or bundled to a thread. It may also be metallic wire or wire bundle preferably containing iron, nickel, chromium, molybdenum, platinum, tantalum, niobium and / or tungsten to be used, wherein the strands may consist of round or flat wire. It can also be a foil made of metal. It can also be a meandering metallic tape. It can also be a snail-shaped metallic tape.

In a further embodiment, at least one fabric layer of a hybrid textile may be contained in the fiber framework of the OCMC. The conductive threads made of electrically conductive material contained therein function as heating conductors. Specifically, the first supporting structure may comprise a hybrid OCMC layer comprising the fiber framework of OCMC and additionally the heating conductor in the form of conductive threads, such as metallic threads and/or carbon fibers and/or silicon carbide fibers, woven into the OCMC structure. Such a hybrid OCMC layer may be denoted as hybrid textiles herein. Metallic threads in hybrid textiles may comprise fibers having a fiber thickness of 10 microns to 150 microns, preferably 15 microns to 100 microns, more preferably 20 microns to 70 microns. These fibers may be twisted into strands. A strand may comprise 4 to 100 fibers, preferably 6 to 50 fibers and particularly preferably 10 to 30 fibers. The ratio of weft threads of metal fibers to weft threads of oxide ceramic fibers may be from 20:1 to 1:20, preferably from 5:1 to 1:10 and particularly preferably from 1:1 to 1:5. Threads of carbon fibers or silicon carbide fibers in hybrid textiles may comprise fibers having a fiber thickness of 3 microns to 15 microns, preferably 5 microns to 10 microns. The fibers may be bundled into a thread. A thread may comprise 1000 to 24000 fibers, preferably 1000 to 6000 fibers. According to DIN 609-5 - Part 1, the yarn thickness may be from 50 Tex to 1600 Tex, preferably from 50 Tex to 400 Tex. The ratio of the weft threads made of carbon fibers or silicon carbide fibers to weft threads of oxide ceramic fibers may be from 20: 1 to 1: 20, preferably from 5: 1 to 1: 10 and particularly preferably from 1: 1 to 1: 5.

The heating panel may be configured for being powered directly, e.g. by applying at least one electrical voltage to the resistive wire of the heating conductor. The heating conductor may comprise at least two ends. The ends may be used as electrical contacts for contacting the heating panel, in particular the heating conductor, with a power line. The term "power line" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary power supply, e.g. a voltage source.

The heating panel may be contacted by the power line in a series connection or on a parallel connection. For example, a power may be from 10 kW to 2000 kW, 20 kW to 1000 kW, 50 kW to 500 kW. For example, an electrical current may be from 1 to 1000 A, preferably from 2 to 500 A, more preferably from 10 to 100 A. For example, an electric current density may be from 1 A/mm² to 500 A/mm², preferably from 5 A/mm² to 100 A/mm². For example, a voltage gradient may be from 1 V/m to 100 V/m, preferably from 5 V/m to 50 V/m. For example, a voltage may be from 10 V to 50000 V, preferably from 20 V to 10000 V, more preferably from 50 V to 5000 V.

In an apparatus for heating a feedstock, a plurality of heating panels may be used, e.g. connected in series. The heating panels may be operated with identical or different voltage or current. The apparatus may comprise at least one temperature sensor, e.g. for each heating panel or a group of heating panels, for controlling voltage depending on a detected temperature and a target temperature.

The ends of the heating conductor may have an extended cross section. This may allow forming cold ends for contacting of the heating element to the power line. For example, a cross section ratio cold ends to the heating conductor may be from 1 to 100, preferably from 2 to 50, more preferably from 5 to 20. However, also other dimensions may be feasible.

Additionally or alternatively, the heating panel may be configured for being powered indirectly. For example, the first supporting structure may be configured as susceptor for coupling of inductive currents or microwaves to the heating conductor.

The heating panel may specifically comprise at least one layer stack. The term "layer stack" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arbitrary sequence of at least two layers which are applied to one another directly or with the interposition of one or more intermediate layers.

The layer stack may comprise several layers of the same material. Furthermore, the layer stack may have layers of different materials. Other embodiments are also feasible in principle. In particular, the layer stack may have at least two layers. Another number of layers is also conceivable in principle. The layers may be delimited from each other by interfaces. The interfaces may be planar or textured. The "layer stack" may therefore also be referred to as a "layer structure".

The layers of the layer stack may be arranged on top of each other. The term "superimposed" as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to an arrangement of a first surface of a first layer to a second surface of a second layer, wherein the two surfaces are arranged opposite to each other. In particular, the first surface and the second surface may be in direct contact with each other. In particular, the second layer may rest on the first layer with the first surface and the sec-

ond surface at least partially in contact. In such an arrangement, the second layer may, for example, have smaller dimensions, in particular a smaller length and/or width, than the first layer or vice versa. Thereby, parts of the second surface may be uncovered by the first layer or vice versa. Furthermore, the first layer and the second layer may be arranged offset to each other, i.e. a part of the second layer may protrude over an edge of the first layer or vice versa.

The heating panel may comprise at least one second supporting structure, specifically at least one second supporting structure of OCMC. With regard to properties of the second supporting structure, reference is made to the description of the first supporting structure above. The second supporting structure may exemplarily be identical to the first support structure. However, the first supporting structure and the second supporting structure may also be different from each other such as by differing from each other by at least one parameter.

Specifically, the heating conductor may be sandwiched in between the first supporting structure and the second supporting structure of OCMC. Thus, the heating panel may comprise a layer stack comprising a layer of the first supporting structure, a layer of the heating conductor and a layer of the second supporting structure in the given order. However, the layer stack may further comprise additional layers which may be arranged between the layer of the first supporting structure and the layer of the heating conductor or between the layer of the second supporting structure and the layer of the heating conductor. Also other embodiments may be feasible.

The heating panel, specifically the layered structure, may comprise at least one top layer. For example, the top layer may be arranged onto the second supporting structure. In case of omitting a second supporting structure, e.g. of OCMC, for example, the heating conductor may be sandwiched in between the first supporting structure and the top layer.

Additionally or alternatively, the heating panel, specifically the layered structure, may comprise at least one bottom layer. The first supporting structure may be arranged onto the bottom layer. The terms “top layer” and “bottom layer” may refer to the outermost layers of the heating panel. The top layer and the bottom layer may be located on opposing sides of the heating panel.

The first supporting structure may have at least one first side and at least one opposing second side. The heating conductor, and optionally second supporting layer and/or top layer, may be located on the first side. The bottom layer may be arranged on the second side. However, also other embodiments may be possible. Thus, one or more intermediate layers may be arranged between the heating conductor and the first side of the first supporting structure and/or one or more intermediate layers may be arranged between the bottom layer and the second side of the first supporting structure.

The second supporting structure may have at least one first side and at least one opposing second side. The top layer may be arranged on the first side. The heating conductor, and optionally further layers of the heating panel, may be located on the second side. However, also other embodiments may be possible. Thus, one or more intermediate layers may be arranged between

the heating conductor and the second side of the second supporting structure and/or one or more intermediate layers may be arranged between the top layer and the first side of the second supporting structure.

- 5 The heating conductor may have least one first side and at least one opposing second side. The top layer may be located on the first side and the first supporting structure may be arranged on the second side. However, also other embodiments may be possible. Thus, one or more intermediate layers may be arranged between the top layer and the first side of the heating conductor and/or one or more intermediate layers may be arranged between the first supporting structure and the second side of the heating conductor.

The top layer and/or the bottom layer may be monolithic crystalline or amorphous. Specifically, the top layer and/or the bottom layer may comprise at least one stoneware glaze such as, exemplarily, Botz stoneware glaze 9870.

- 15 In a further aspect of the present invention a use of a heating panel according to the present invention is proposed, for a purpose of radiation heating, preferably radiation heating in an industrial furnace, more preferably radiation heating in a reactor furnace. With regard to embodiments and definitions, can be made to the above description of the heating panel.

- 20 In a further aspect of the present invention, an apparatus for heating a feedstock is proposed. The apparatus comprises at least one heating panel according to the present invention. With regard to embodiments and definitions, can be made to the above description of the heating panel. The apparatus comprises at least one pipeline for receiving the feedstock. The apparatus comprises voltage source, which is connected to the heating panel and is designed for applying at least one voltage to the heating panel thereby generating heat. The heating panel and the pipeline are arranged such that the heating panel heats the pipeline for heating the feedstock by heat radiation.

- 30 The term “feedstock”, also denoted as feed, as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized meaning. The term specifically may refer, without limitation, to a stream of material which is fed to the pipeline. For example, the feedstock may be a gaseous and/or liquid medium, e.g. a fluid. The feedstock may for example be selected from the group consisting of: water, steam, a combustion air, a hydrocarbon mixture, a hydrocarbon to be cracked. For example, the feedstock may be a hydrocarbon to be thermally cracked, in particular a mixture of hydrocarbons to be thermally cracked. For example, the feedstock may be water or steam and additionally comprise a hydrocarbon to be thermally cracked, in particular a mixture of hydrocarbons to be thermally cracked. The feedstock may for example be a preheated mixture of hydrocarbons to be thermally cracked and steam. Other fluids are also conceivable.

The term “pipeline” as used herein is a broad term and is to be given its ordinary and customary meaning to a person of ordinary skill in the art and is not to be limited to a special or customized

meaning. The term specifically may refer, without limitation, to an arbitrary device configured for receiving and transporting the feedstock. The geometry and/or surfaces and/or material of the pipeline may be dependent on a feedstock to be transported.

- 5 The pipeline may be designed as a reaction pipe, in particular a heating pipe. The apparatus may be part of an industrial reactor furnace, in particular of an electrical reactor furnace. The industrial reactor furnace may be configured to carry out at least one process selected from the group consisting of: performing at least one endothermic reaction; cracking; steam cracking; steam reforming; alkane dehydrogenation; heating, preheating; superheating or for intermediate
 10 superheating of steam; styrene production by ethylbenzene dehydrogenation; production of acetylene; catalytic cracking; splitting ammonia for hydrogen production; hydrocyanic acid synthesis from hydrocarbons and ammonia
 ammonia cracking ($\text{NH}_3 \rightarrow 1/2\text{N}_2 + 3/2\text{H}_2$),
 methane steam reforming: ($\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$),
 15 cyanic acid from methane and ammonia (BMA) ($\text{CH}_4 + \text{NH}_3 \rightarrow \text{HCN} + 3\text{H}_2$),
 formamide cleavage ($\text{HCONH}_2 \rightarrow \text{HCN} + \text{H}_2\text{O}$),
 Alkane dehydrogenation ($\text{C}_n\text{H}_{(2n+2)} \rightarrow \text{C}_n\text{H}_{(2n)} + \text{H}_2$, $n=2,3,4$),
 styrene synthesis ($\text{C}_8\text{H}_{10} \rightarrow \text{C}_8\text{H}_8 + \text{H}_2$), or
 Cyclohexane dehydrogenation ($\text{C}_6\text{H}_{12} \rightarrow \text{C}_6\text{H}_6 + 3\text{H}_2$).

20 The apparatus may comprise a plurality of pipelines. The apparatus may comprise L pipelines, where L is a natural number greater than or equal to two. For example, the apparatus may comprise at least two, three, four, five or even more pipelines. The apparatus may for example comprise up to a hundred pipelines. The pipelines may be configured identically or differently.

25 The pipelines may comprise symmetrical and/or asymmetrical pipes and/or combinations thereof. In a purely symmetrical configuration, the apparatus may comprise pipelines of an identical type of pipe. "Asymmetrical pipes" and "combinations of symmetrical and asymmetrical pipes" may be understood as meaning that the apparatus may comprise any combination of
 30 types of pipe, which may for example also be connected as desired in parallel or in series. A "type of pipe" may be understood as meaning a category or type of pipeline characterized by certain features. The type of pipe may be characterized at least by one feature selected from the group consisting of: a horizontal configuration of the pipeline; a vertical configuration of the pipeline; a length in the inlet (L1) and/or outlet (L2) and/or transition (L3); a diameter in the inlet
 35 (d1) and outlet (d2) and/or transition (d3); the number n of passes; the length per pass; the diameter per pass; the geometry; the surface; and the material. The apparatus may comprise a combination of at least two different types of pipe which are connected in parallel and/or in series. For example, the apparatus may comprise pipelines of different lengths in the inlet (L1) and/or outlet (L2) and/or transition (L3). For example, the apparatus may comprise pipelines
 40 with an asymmetry of the diameters in the inlet (d1) and/or outlet (d2) and/or transition (d3). For example, the apparatus may comprise pipelines with a different number of passes. For example, the apparatus may comprise pipelines with passes with different lengths per pass and/or

different diameters per pass. In principle, any combinations of all types of pipe in parallel and/or in series are possible.

The apparatus may comprise a plurality of inlets and/or outlets and/or production streams. The pipelines of different or identical types of pipe may be arranged in parallel and/or in series with a plurality of inlets and/or outlets. Pipelines can be present in various types of pipe in the form of a construction kit and may be selected and combined as desired, dependent on an intended use. By using pipelines of different types of pipe, more accurate temperature control and/or an adaptation of the reaction when there is a fluctuating feed and/or a selective yield of the reaction and/or an optimized process technology can be made possible.

The pipelines may comprise identical or different geometries and/or surfaces and/or materials. The pipelines may be through-connected, and thus form a pipe system for receiving the fluid. A "pipe system" may be understood as meaning a device comprising at least two pipelines, in particular connected to one another. The pipe system may comprise incoming and outgoing pipelines. The pipe system may comprise at least one inlet for receiving the feedstock. The pipe system may comprise at least one outlet for discharging the feedstock. "Through-connected" may be understood as meaning that the pipelines are in fluid connection with one another. Thus, the pipelines may be arranged and connected in such a way that the feedstock flows through the pipelines one after the other. However parallel flowing may be possible. The pipelines may be connected parallel to one another in such a way that the feedstock can flow through at least two pipelines in parallel. The pipelines may be designed in such a way as to transport different feedstock in parallel. In particular, the pipelines connected in parallel may comprise geometries and/or surfaces and/or materials that are different from one another for transporting different feedstock. In particular for the transport of a feedstock, a number or all of the pipelines may be configured as parallel, so that the feedstock can be divided among those pipelines configured as parallel. Combinations of a series connection and a parallel connection are also conceivable.

The apparatus comprises at least one power source, which is connected to the heating panel. The power source may be an arbitrary power source such as a direct current (DC) voltage source and/or an alternating current (AC) voltage source. The apparatus may comprise a plurality of power sources. The apparatus may comprise 2 to M different power sources, where M is a natural number greater than or equal to three. The power source may either be controlled or uncontrolled. The power source may be configured with or without the possibility of controlling at least one electrical output variable. An "output variable" may be understood as meaning a current and/or a voltage value and/or a current and/or a voltage signal. The power sources may be electrically controllable independently of one another. For example, a different current may be generated in the respective heating panel and different temperatures reached in the pipelines.

The apparatus according to any of the preceding claims referring to an apparatus, wherein the apparatus is configured for heating the feedstock to a temperature range from 200 °C to 1700 °C, preferably from 300 °C to 1400 °C, more preferably from 400 °C to 875 °C.

The apparatus may, for example, be part of a steam cracker. "Steam cracking" may be understood as meaning a process in which longer-chain hydrocarbons, for example naphtha, propane, butane and ethane, as well as gas oil and hydrowax, are converted into short-chain hydrocarbons by thermal cracking in the presence of steam. In steam cracking, hydrogen, methane, ethene and propene can be produced as the main product, as well as inter alia butenes and pyrolysis benzene. The steam cracker may be designed for heating up the feedstock to a temperature in the range of 550°C to 1100°C.

For example, the apparatus may be part of a reformer furnace. "Steam reforming" may be understood as meaning a process for producing hydrogen and carbon oxides from water and carbon-containing feedstocks, in particular hydrocarbons such as natural gas, light gasoline, or biogas. For example, the feedstock may be heated up to a temperature in the range of 200°C to 1000°C, preferably of 400°C to 900°C.

For example, the apparatus may be part of a device for alkane dehydrogenation. "Alkane dehydrogenation" may be understood as meaning a process for producing alkenes by dehydrogenating alkanes, for example dehydrogenating butane into butenes (BDH) or dehydrogenating propane into propene (PDH). The device for alkane dehydrogenation may be designed for heating up the feedstock to a temperature in the range of 400°C to 700°C.

However, other temperatures and temperature ranges are also conceivable.

The heating panel may have many advantages over known heating panels.

A ribbon-shaped metallic heating conductor which may exemplarily be made of iron- or nickel-based alloy may be embedded between two OCMC half shells. In this way, a directly electrically heated panel may be realized. A ribbon-shaped heating conductor may be supported by the OCMC half shells through a force- and / or a form-fitting connection, which may ensure a necessary dimensional stability of the heating panel. The ribbon-shaped heating conductor may be cut in such a way that a power density is locally adapted to a power requirement along cracker coils. In particular, the ends are shaped to form cold ends for the contacting of the heating conductor to the power line. Surprisingly, the heating panel is commonly stable despite of different thermal expansion coefficients of metal and OCMC.

The heating panel may be self-supporting, thermally and chemically resistant under intended operating conditions. The heating conductor may be formed by a thin metallic tape. Heat may be released with a moderate radiation density and a correspondingly moderate overtemperature of the metallic tape. The heating conductor may be operated at high temperatures, specifically up to 1300°C, despite the fact that it is losing its strength almost completely. The surface-specific ohmic resistance of the heating conductor may be specifically adjusted over a wide range by a cutting pattern of the metallic tape and may be varied. The surface-specific ohmic resistance ρ_A may be defined as follows:

$$\rho_A = \frac{R_{hp}}{A_{hp}} = \rho_\Omega \cdot \frac{\varphi_{hc}}{b_{hc}^2 \cdot s_{hc}}$$

wherein ρ_A in $\frac{\Omega}{m^2}$ being a surface-specific ohmic resistance of a heating panel, R_{hp} in Ω being an ohmic resistance of the heating panel, A_{hp} in m^2 being a surface area of the heating panel, ρ_Ω in $\Omega \cdot m$ being a specific ohmic resistance of heating conductor, φ_{hc} in $\frac{m^2}{m^2}$ being a coverage ratio of the heating conductor on the heating panel, b_{hc} in m being a width of the heating conductor track, s_{hc} in m being a thickness of the heating conductor track.

The surface-specific ohmic resistance may be from $0,1 \frac{\Omega}{m^2}$ to $10000 \frac{\Omega}{m^2}$, preferably from $1 \frac{\Omega}{m^2}$ to $1000 \frac{\Omega}{m^2}$, more preferably from $5 \frac{\Omega}{m^2}$ to $500 \frac{\Omega}{m^2}$.

As a result, the power density can be distributed specifically over the surface of the heating panel. The cold ends may be integrated to the heating panel, enabling a feasible connection to the power line. Further, the heating panel may feature a large specific surface area. This facilitates an optional intensification via convective heat transfer to a circulating surrounding gas.

The convective heat transport may act parallel to a heat radiation. It may contribute to reducing an overheating of the heating panel. The efficiency of heat radiation may be improved by blacking the surface of an OCMC shell. An effective surface of the heating panel may be increased by corrugating its shape. a thermal radiation may be intensified by using a fabric with an open weaving pattern as fiber framework for the OCMC shell. Instead of applying a metallic tape, a heating conductor may be plated onto the OCMC shell.

Summarizing and without excluding further possible embodiments, the following embodiments may be envisaged:

Embodiment 1. A heating panel comprising at least one layered structure, wherein the layered structure comprises at least one heating conductor embedded in a first supporting structure of Oxide Ceramic Matrix Composite (OCMC), wherein the heating panel has a normalized shell thickness $S_{norm} = \frac{s}{D_{eq}}$ from 0.0001 to 0.1, with s being a thickness of the panel and $D_{eq} = 4 \frac{A}{U}$ with A being a surface area of the heating panel and U being a perimeter of the surface area.

Embodiment 2. The heating panel according to the preceding embodiment, wherein the normalized shell thickness of the heating panel is from 0.0005 to 0.03.

Embodiment 3. The heating panel according to any one of the preceding embodiments, wherein the thickness of the heating panel is from 0.5 mm to 10 mm.

Embodiment 4. The heating panel according to any one of the preceding embodiments, wherein the heating panel has a geometry selected from the group consisting of: a planar geometry, an arched geometry, a regular or irregular geometry.

- Embodiment 5. The heating panel according to any one of the preceding embodiments, wherein the heating panel comprises a second supporting structure of OCMC, wherein the heating conductor is sandwiched in between the first supporting structure and a second supporting structure.
- Embodiment 6. The heating panel according to the preceding embodiment, wherein the layered structure comprises at least one top layer.
- Embodiment 7. The heating panel according to the preceding embodiment, wherein the top layer is arranged onto the second supporting structure.
- Embodiment 8. The heating panel according to any one of the two preceding embodiments, wherein the layered structure comprises at least one bottom layer, wherein the first supporting structure is arranged onto the bottom layer.
- Embodiment 9. The heating panel according to any one of the three preceding embodiments, wherein the heating panel comprises the at least one top layer, wherein the heating conductor is sandwiched in between the first supporting structure and the top layer.
- Embodiment 10. The heating panel according to any one of the three preceding embodiments, wherein the top layer and/or the bottom layer are monolithic crystalline or amorphous, wherein the top layer and/or the bottom layer comprise at least one stoneware glaze.
- Embodiment 11. The heating panel according to any one of the preceding embodiments, wherein the heating conductor and the first supporting structure are connected by one or more of at least one force-fit connection, at least one form fit connection, or at least one material closure.
- Embodiment 12. The heating panel according to any one of the preceding embodiments, wherein the OCMC has a matrix composition selected from the group consisting of: $\text{Si}_x\text{M}_y\text{O}_z$, $\text{Si}_x\text{M}_1\text{yM}_2\text{wO}_z$, $\text{Si}_x\text{B}_y\text{N}_z\text{C}_w$, AlN , MxOy and mixtures of oxides ($\text{M}_1\text{xO}_y/\text{M}_2\text{wO}_z$).
- Embodiment 13. The heating panel according to any one of the preceding embodiments, wherein the OCMC has oxide ceramic reinforcing fibers comprising at least one material selected from the group consisting of: mullite, Al_2O_3 , a combination of mullite and Al_2O_3 .
- Embodiment 14. The heating panel according to any one of the preceding embodiments, wherein the first supporting structure has a fabric, a mesh, a woven or a knitted structure.
- Embodiment 15. The heating panel according to any one of the preceding embodiments, wherein the heating conductor comprises at least one metallic material selected from the

group consisting of: an iron-based alloy, a nickel-based alloy, a platinum group metal (PGM); a refractory metal; at least one ferritic iron-chromium-aluminum (FeCrAl) alloy; or one alloy having a material number according to DIN 17007-2:1961-09: n1.m1m2m3m4, with n1 being a digit selected from the group 1, 2, 3, and preferably a digit from the group 1 and 2, with m1 being a digit selected from the group 0, 1, 3, 4, 8, preferably a digit selected from the group 3 and 4, and particularly preferably the digit 4, with m2 being a digit selected from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, preferably a digit selected from the group 5, 6, 7, 8, 9 and particularly preferably a digit selected from the group 7, 8, 9, with m3 and m4, preferably each independently, being a digit selected from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or wherein the heating conductor comprises at least one conductive ceramic, wherein the heating element comprises at least one material selected from the group consisting of: carbon, such as graphite or carbon fibers; carbides, e.g. silicon carbide (SiC) or zirconium carbide (ZrC); nitrides, e.g. silicon nitride (Si₃N₄); silicides, e.g. molybdenum disilicide (MoSi₂); binary oxides, e.g. Ytria Stabilized Zirconia (YSZ), Magnesia Stabilized Zirconia (MSZ), titanium oxides (TiO); ternary oxides, e.g. Perovskite, ferrites, or the like.

Embodiment 16. The heating panel according to any one of the preceding embodiments, wherein the heating conductor is plated by one or more of molding, printing or coating on the first supporting structure.

Embodiment 17. The heating panel according to any one of the preceding embodiments, wherein the heating conductor comprises a tape.

Embodiment 18. The heating panel according to any one of the preceding embodiments, wherein the heating conductor comprises an elliptic, circular, or prismatic cross section.

Embodiment 19. The heating panel according to any one of the preceding embodiments, wherein the heating conductor comprises a rectangular, a circular, a snail-shaped, or a meandering structure in a top view.

Embodiment 20. The heating panel according to any one of the preceding embodiments, wherein ends of the heating conductor have an extended cross section to form cold ends for contacting of the heating panel to a power line.

Embodiment 21. The heating panel according to any one of the preceding embodiments, wherein the heating panel is configured for being powered indirectly, wherein the first supporting structure is configured as susceptor for coupling of inductive currents or microwaves to the heating conductor.

Embodiment 22. Use of a heating panel according to any one of the preceding embodiments relating to a heating panel, for a purpose of radiation heating, preferably radiation heating in an industrial furnace, more preferably radiation heating in a reactor furnace.

Embodiment 23. An apparatus for heating a feedstock comprising at least one heating panel according to any one of the preceding embodiments relating to a heating panel, wherein the apparatus comprises at least one pipeline for receiving the feedstock, wherein the apparatus comprises at least one power source, which is connected to the heating panel and is designed for applying at least one voltage to the heating panel thereby generating heat, wherein the heating panel and the pipeline are arranged such that the heating panel heats the pipeline for heating the feedstock by heat radiation.

Embodiment 24. The apparatus according to the preceding embodiment, wherein the apparatus is part of an industrial reactor furnace, wherein the industrial reactor furnace is configured to carry out at least one process selected from the group consisting of: performing at least one endothermic reaction; cracking; steam cracking; steam reforming; alkane dehydrogenation; heating, preheating; superheating or for intermediate superheating of steam; styrene production by ethylbenzene dehydrogenation; production of acetylene; catalytic cracking; splitting ammonia for hydrogen production; hydrocyanic acid synthesis from hydrocarbons and ammonia;
ammonia cracking ($\text{NH}_3 \rightarrow 1/2\text{N}_2 + 3/2\text{H}_2$),
methane steam reforming: ($\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$),
cyanic acid from methane and ammonia (BMA) ($\text{CH}_4 + \text{NH}_3 \rightarrow \text{HCN} + 3\text{H}_2$),
formamide cleavage ($\text{HCONH}_2 \rightarrow \text{HCN} + \text{H}_2\text{O}$),
Alkane dehydrogenation ($\text{C}_n\text{H}_{(2n+2)} \rightarrow \text{C}_n\text{H}_{(2n)} + \text{H}_2$, $n=2,3,4$),
styrene synthesis ($\text{C}_8\text{H}_{10} \rightarrow \text{C}_8\text{H}_8 + \text{H}_2$),
Cyclohexane dehydrogenation ($\text{C}_6\text{H}_{12} \rightarrow \text{C}_6\text{H}_6 + 3\text{H}_2$).

Embodiment 25. The apparatus according to any of the preceding embodiments referring to an apparatus, wherein the apparatus is configured for heating the feedstock to a temperature range from 200 °C to 1700 °C, preferably from 300 °C to 1400 °C, more preferably from 400 °C to 875 °C.

Brief description of the figures

Further optional details and features of the invention are evident from the description of preferred exemplary embodiments which follows in conjunction with the dependent claims. In this context, the particular features may be implemented alone or with features in combination. The invention is not restricted to the exemplary embodiments. The exemplary embodiments are shown schematically in the figures. Identical reference numerals in the individual figures refer to identical elements or elements with identical function, or elements which correspond to one another with regard to their functions.

Specifically, in the figures:

Figures 1A and 1B show an exemplary embodiment of a layer stack of a heating panel according to the present invention in a perspective view (Figure 1A) and in a cross-sectional view (Figure 1B), wherein for the sake of clarity, in Figure 1A the scale in the z-coordinate is enlarged against the scale in the xy-plane;

Figures 2A to 2C show further exemplary embodiments of a layer stack of a heating panel according to the present invention in cross-sectionals views;

Figure 3 shows an exemplary embodiment of a heating panel in a perspective view; and

Figure 4 shows experimental results.

Exemplary embodiments

Figures 1A and 1B show an exemplary embodiment of a layer stack 110 of a heating panel 112 according to the present invention in a perspective view (Figure 1A) and in a cross-sectional view (Figure 1B).

The layer stack 110 may comprise at least one bottom layer 114 and at least one first supporting structure of OCMC 116. The first supporting structure of OCMC 116 may be arranged onto the bottom layer 114. At least one heating conductor 118 is embedded in the first supporting structure of OCMC 116. Ends 120 of the heating conductor 118 may have an extended cross section to form cold ends 122 for contacting of the heating conductor to a power line. Further, the layer stack 110 may comprise a second supporting structure of OCMC 124 and at least one top layer 126 (not shown in Figure 1A). The second supporting structure of OCMC 124 may be arranged onto the heating conductor 118. The top layer 126 may be arranged onto the second supporting structure of OCMC 124.

Figures 2A to 2C show further exemplary embodiments of a layer stack 110 of a heating panel 112 according to the present invention in cross-sectionals views. The embodiments according to Figures 2A to 2C correspond at least partially to the embodiments according to Figures 1A and 1B. Thus, reference is made to the description of Figures 1A and 1B above.

In the embodiment according to Figure 2A, the layer stack 110 may exclusively comprise the first supporting structure of OCMC 116, the heating conductor 118 and the second supporting structure of OCMC 124. The heating conductor 118 is embedded in the first supporting structure of OCMC 116. The heating conductor 118 may be sandwiched between the first supporting structure of OCMC 116 and the second supporting structure of OCMC 124.

In the embodiment according to Figure 2B, the layer stack 110 may exclusively comprise the bottom layer 114, the first supporting structure of OCMC 116, the heating conductor 118 and

the top layer 126. The first supporting structure of OCMC 116 may be arranged onto the bottom layer 114. The heating conductor 118 is embedded in the first supporting structure of OCMC 116. The heating conductor 118 may be sandwiched between the first supporting structure of OCMC 116 and the top layer 126.

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In the embodiment according to Figure 2C, the layer stack 110 may exclusively comprise the first supporting structure of OCMC 116 and the heating conductor 118. The heating conductor 118 is embedded in the first supporting structure of OCMC 116.

10 Figure 3 shows an exemplary embodiment of a heating panel in a perspective view.

The heating panel 112 may have an arched geometry. The heating panel 112 comprises at least one layered structure 128. The layered structure 128 comprises the at least one heating conductor 118 embedded in the first supporting structure of Oxide Ceramic Matrix Composite (OCMC). A layer stack 110 of the heating panel 112 may refer to the layer stack 110 according to Figure 2A. Thus, reference to the description of Figure 2A above is made.

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The heating panel 112 has a normalized shell thickness $S_{norm} = \frac{s}{D_{eq}}$ from 0.0001 to 0.1, with s being a thickness of the panel $D_{eq} = 4 \frac{A}{U}$ with A being a surface area of the heating panel and U being a perimeter of the surface area. The surface area may refer to the total area that the surface of the object occupies. The surface of the heating panel 112 may be planar.

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The fabrication of a flat heating panel can be regarded as surprising. It was expected that embedding a metallic heating conductor would disrupt a bond between layers of the layer stack and lead to delamination. Surprisingly, the result is a stable, solid heating panel with high strength throughout the volume.

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Example

30 Figure 4 shows experimental results. A rectangular heating panel 112 was used having the dimensions 400mm x 200mm x 3mm (length x width x thickness). The heating panel 112 in this experiment comprised a heating conductor 118 made of an alloy listed under material number 1.4767. The heating conductor 118 had a thickness of 0.11 mm. An active heating surface of the heating panel 112 was (276 x 154)mm². The heating conductor 118 was embedded in a rectangular OCMC plate. The OCMC plate of the type N610-DF11-1500/ FW12 of the manufacturer WPS. The fiber framework comprised eight layers of a fabric of the type NEXTEL 610 DF11-1500 of the manufacturer 3M. The heating conductor 118 was embedded between the fourth and fifth fabric layers. The heating conductor 118 was positioned in a way, that the two 60 mm wide contact strips protruded 180 mm beyond the end of the heating panel 112.

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After lamination, the heating panel 112 was dried for 12 hours in a drying oven and then fired. The temperature program during firing corresponded to the standard program for the production

of components made of FW12: heating with a temperature ramp from 250 K/h to 1200°C and holding to 1200°C for 5 hours. Subsequently, the heating panel 112 was stored in an oven with the heating switched off until it cooled down to 100°C.

- 5 The heating panel 112 was contacted by nickel strands type GL-Ni 4.0mm² of the supplier Litzenladen. For this purpose, an 8 mm hole was drilled at an end of each contact strip and an end of the nickel strand was attached by a screw to the contact strip.

10 The resistance of the heating conductor 118 was measured with a Fluke type 88-5 digital multi-meter between the two contact points and was 8.1 ohms at ambient temperature. The heating conductor 118 was connected to a DC power source type HEA-PS 81000-30 3U of the manufacturer Heiden electronics GmbH. The heating output of the heating panel 112 was controlled by the voltage at the power source. The temperature at the surface of the heating panel 112 was measured by type N thermocouples and controlled by manually adjusting the output voltage at the power source.

20 For the functional test, the heating plate was wrapped in a 5mm thick mat of the type CALSI-TRA CP 1250 of the manufacturer RATH & Co Ltd and placed between two calcium silicate plates of 25mm thickness, type MICROCAL® 1100 of the manufacturer SILCA. In a systematic series of experiments, the heating panel 112 varied the temperature at the surface of the heating plate cyclically between 600°C and 1200°C, wherein within each cycle the temperature was kept for 30 minutes at 1200 °C as shown in Figure 4. In steady state operation at 1200°C, the heating panel 112 was supplied with a voltage of 240V. The current was 28 amps. Thus, a power of 6720 Watt was generated in the heating panel 112. The surface-related power density in relation to the active heating surface was 150 kW/m². Four cycles were conducted. The heating panel 112 was inspected afterwards. It can be observed that the heating panel 112 has retained its functionality and its structural integrity unchanged.

List of reference numbers

110	layer stack
112	heating panel
114	bottom layer
116	first supporting structure of OCMC
118	heating conductor
120	end
122	cold end
124	second supporting structure of OCMC
126	top layer
128	layered structure

Claims

1. A heating panel (112) comprising at least one layered structure (128), wherein the layered structure (128) comprises at least one heating conductor (118) embedded in a first supporting structure of Oxide Ceramic Matrix Composite (OCMC) (116), wherein the heating panel (112) has a normalized shell thickness $S_{norm} = \frac{s}{D_{eq}}$ from 0.0001 to 0.1, with s being a thickness of the panel and $D_{eq} = 4 \frac{A}{U}$ with A being a surface area of the heating panel and U being a perimeter of the surface area.
2. The heating panel (112) according to the preceding claim, wherein the normalized shell thickness of the heating panel (112) is from 0.0005 to 0.03.
3. The heating panel (112) according to any one of the preceding claims, wherein the thickness of the heating panel (112) is from 0.5 mm to 10 mm.
4. The heating panel (112) according to any one of the preceding claims, wherein the heating panel (112) has a geometry selected from the group consisting of: a planar geometry, an arched geometry, a regular or irregular geometry.
5. The heating panel (112) according to any one of the preceding claims, wherein the heating panel comprises a second supporting structure of OCMC (124), wherein the heating conductor (118) is sandwiched in between the first supporting structure of OCMC (116) and the second supporting structure of OCMC (124).
6. The heating panel (112) according to the preceding claim, wherein the layered structure comprises at least one top layer (126).
7. The heating panel (112) according to the preceding claim, wherein the top layer (126) is arranged onto the second supporting structure of OCMC (124).
8. The heating panel (112) according to any one of the two preceding claims, wherein the layered structure (128) comprises at least one bottom layer (114), wherein the first supporting structure of OCMC (116) is arranged onto the bottom layer (114).
9. The heating panel (112) according to any one of the three preceding claims, wherein the heating panel (112) comprises the at least one top layer (126), wherein the heating conductor (118) is sandwiched in between the first supporting structure of OCMC (116) and the top layer (126).
10. The heating panel (112) according to any one of the preceding claims, wherein the OCMC has a matrix composition selected from the group consisting of: $Si_xM_yO_z$, $Si_xM1_yM2_wO_z$, $Si_xB_yN_zC_w$, AlN , $MxOy$ and mixtures of oxides ($M1_xO_y/M2_wO_z$).

11. The heating panel (112) according to any one of the preceding claims, wherein the OCMC has oxide ceramic reinforcing fibers comprising at least one material selected from the group consisting of: mullite, Al_2O_3 , a combination of mullite and Al_2O_3 .
12. The heating panel (112) according to any one of the preceding claims, wherein the heating conductor comprises at least one metallic material selected from the group consisting of: an iron-based alloy, a nickel-based alloy, a platinum group metal (PGM); a refractory metal; at least one ferritic iron-chromium-aluminum (FeCrAl) alloy; or one alloy having a material number according to DIN 17007-2:1961-09: n1.m1m2m3m4, with n1 being a digit selected from the group 1, 2, 3, and preferably a digit from the group 1 and 2, with m1 being a digit selected from the group 0, 1, 3, 4, 8, preferably a digit selected from the group 3 and 4, and particularly preferably the digit 4, with m2 being a digit selected from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, preferably a digit selected from the group 5, 6, 7, 8, 9 and particularly preferably a digit selected from the group 7, 8, 9, with m3 and m4, preferably each independently, being a digit selected from the group 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or wherein the heating conductor comprises at least one conductive ceramic, wherein the heating element comprises at least one material selected from the group consisting of: carbon such as graphite or carbon fibers; carbides, e.g. silicon carbide (SiC) or zirconium carbide (ZrC); nitrides, e.g. silicon nitride (Si_3N_4); silicides, e.g. molybdenum disilicide (MoSi_2); binary oxides, e.g. Yttria Stabilized Zirconia (YSZ), Magnesia Stabilized Zirconia (MSZ), titanium oxides (TiO); ternary oxides, e.g. Perovskite, ferrites, or the like.
13. Use of a heating panel (112) according to any one of the preceding claims relating to a heating panel (112), for a purpose of radiation heating, preferably radiation heating in an industrial furnace, more preferably radiation heating in a reactor furnace.
14. An apparatus for heating a feedstock comprising at least one heating panel (112) according to any one of the preceding claims relating to a heating panel (112), wherein the apparatus comprises at least one pipeline for receiving the feedstock, wherein the apparatus comprises at least one power source, which is connected to the heating panel (112) and is designed for applying at least one voltage to the heating panel (112) thereby generating heat, wherein the heating panel (112) and the pipeline are arranged such that the heating panel (112) heats the pipeline for heating the feedstock by heat radiation.
15. The apparatus according to the preceding claim, wherein the apparatus is configured for heating the feedstock to a temperature range from 200°C to 1700°C , preferably from 300°C to 1400°C , more preferably from 400°C to 875°C .

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FIG.1A

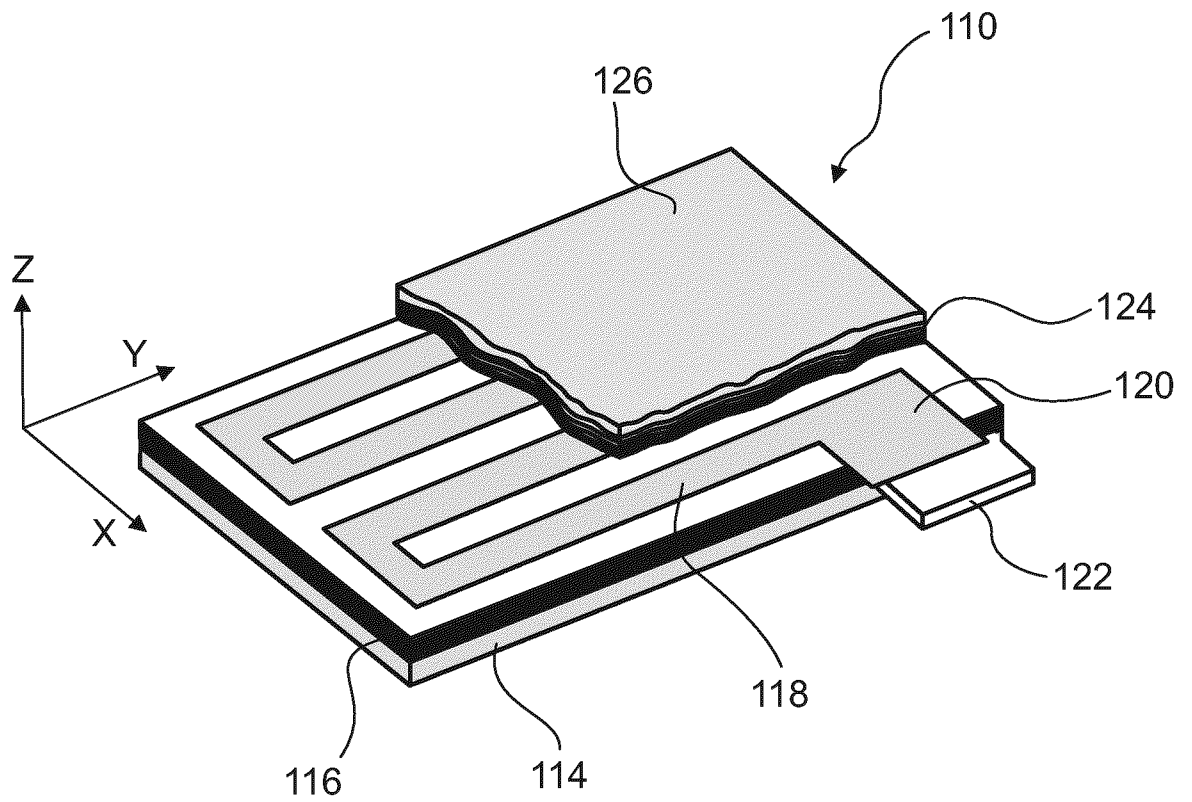


FIG.1B

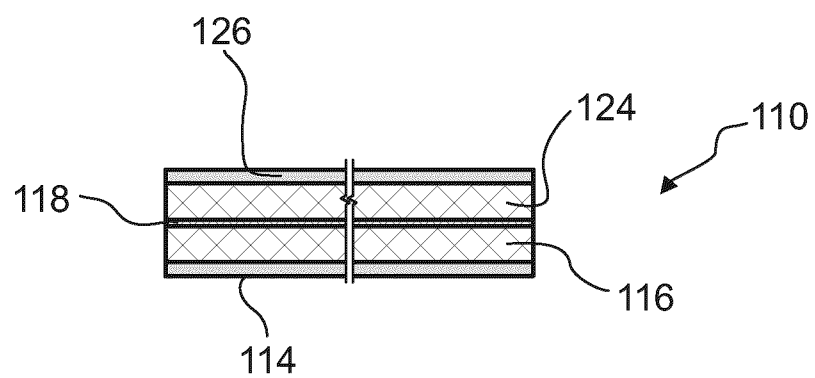


FIG.2A

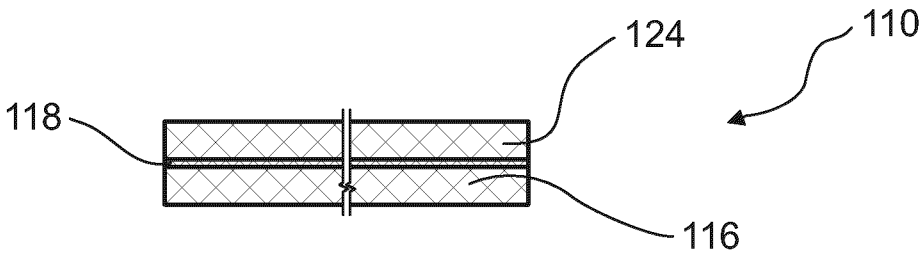


FIG.2B

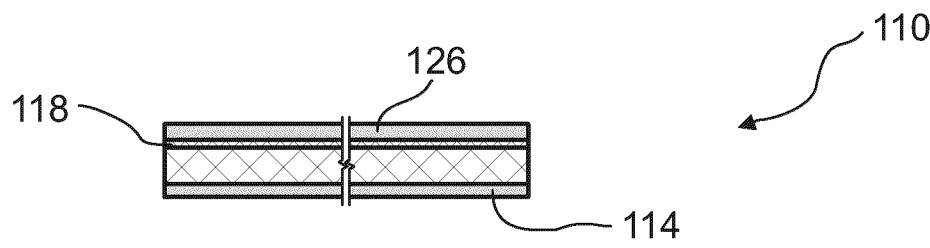


FIG.2C

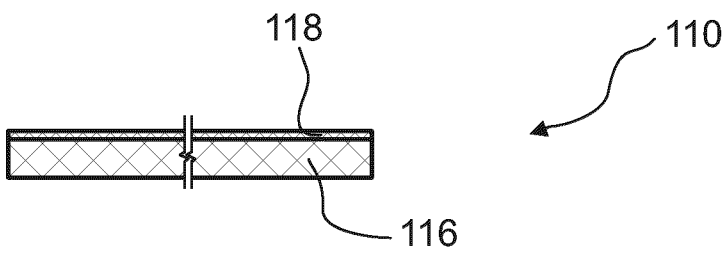


FIG.3

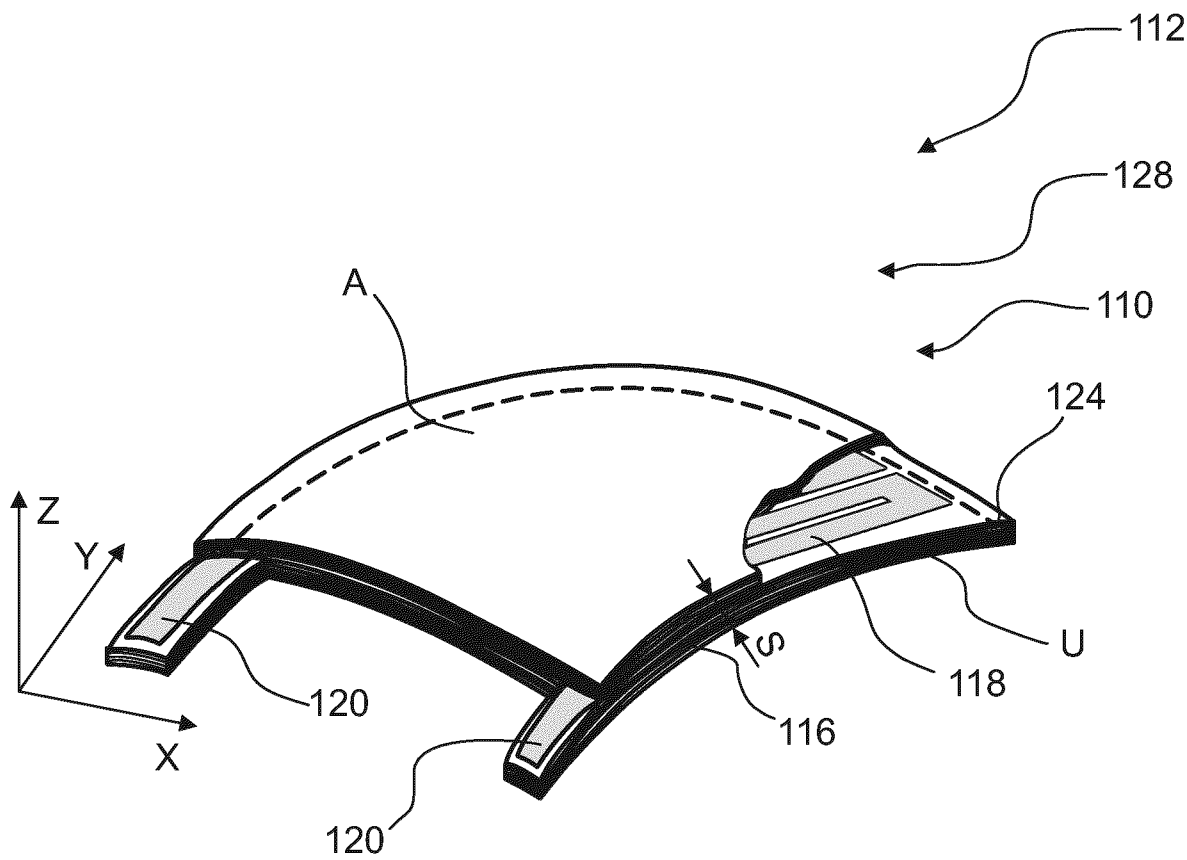
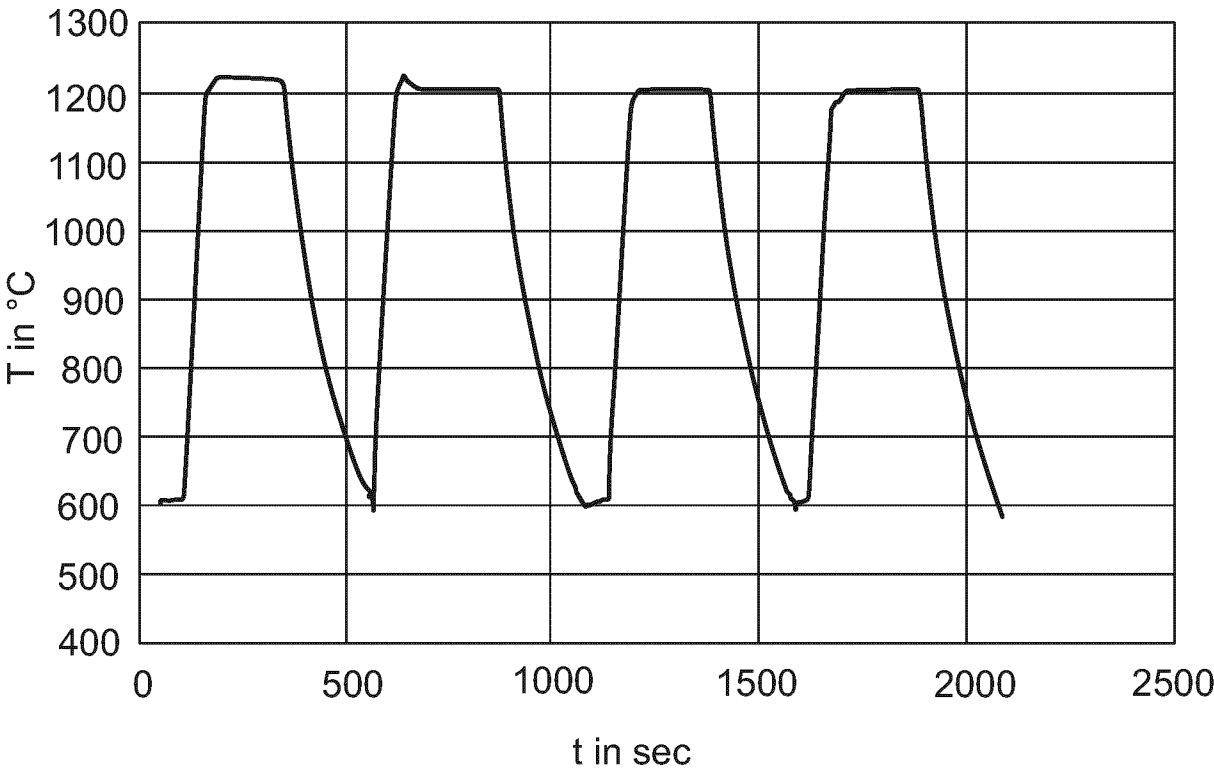


FIG.4



INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/065727

A. CLASSIFICATION OF SUBJECT MATTER

INV. H05B3/28

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

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Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

30 August 2024

Date of mailing of the international search report

16/09/2024

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/065727

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