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(54) **FLOOR OR WALL PANEL AND METHOD OF PRODUCING A FLOOR OR WALL PANEL**

(57) A floor or wall panel comprising a frame made of profiled metal or timber sheet, joists made of profiled metal or timber sheet that connect opposite sides of the frame, wherein voids are present between the joists, a shield made of a metal or timber sheet spaced apart from a fire side of the joists, wherein a clearance is defined between a fire side of the joists and the shield, spacer elements arranged within the clearance between the joists and the shield, and a hardened mineral foam that fills the voids between the joists and that fills the clearance.

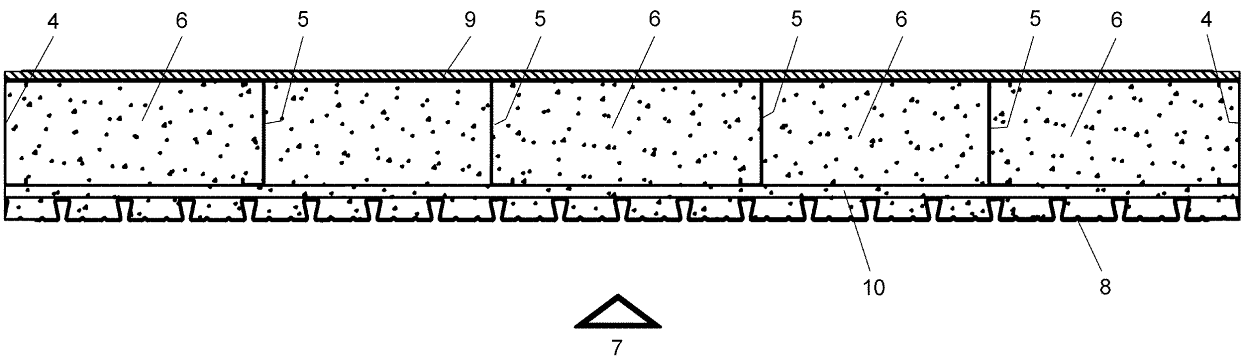

Fig. 2

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Description

[0001] The invention refers to a floor or wall panel and to a method of producing a floor or wall panel.

[0002] Light gauge steel frame construction is a reliable construction method which is broadly used in building construction. Light gauge steel frame construction may be used for constructing load-bearing elements, such as walls and floors, but may also be used for non-structural framing, such as interior partitions or to support external cladding. It offers several advantages such as low weight, buildability, strength, design flexibility and sustainability.

[0003] Light gauge steel frame elements are manufactured from structural steel sheet that is cold formed to obtain various kinds of profiles, e.g., C or U or Z or S shapes, which are able to support heavy loads. A steel frame is manufactured from several steel frame elements, and the steel frame is then clad with dry sheeting on both sides to form a floor or wall panel.

[0004] One disadvantage of floor and wall panels made from light gauge steel frames is that light framed structures allow the passage of sound more readily than the more solid masonry or concrete construction. The main disadvantage is that light gauge steel loses structural capacity as temperatures rise in a fire. Therefore, without protection it will lose structural capacity in <15 minutes.

[0005] Conventionally light gauge steel frames and joists have been protected by special types of plasterboard. Typically, one board gives 30 minutes, 2 boards 60 minutes, 3 boards (12.5mm) 90 minutes and 3 thicker (15mm) boards 120 minutes fire resistance. Plasterboard helps to keep the temperature on the steel down in a fire. After a period of time, the board will break up and fall away, exposing the next board. Once the steel is directly exposed, temperatures will rise very rapidly and the joists will deflect and fail. Once temperatures exceed 250°C, the steel starts to lose structural capacity. Above 500°C failure is normally likely soon after.

[0006] An additional effect is that large temperature gradients develop across the steel, which causes the hot side to bow towards the heat. Particularly in a wall fire test, this bowing effect can cause a steel member to fail at temperatures lower than might be expected.

[0007] Plasterboard, if applied in several layers onto light gauge steel frame elements for achieving acceptable fire resistance, substantially increases the weight of such frame elements, thereby counteracting the original advantage of light gauge steel construction. Plasterboard is typically applied in site environments where control of quality can be an issue, which is a problem for such a performance critical element.

[0008] It would thus be desirable to look for alternative solutions for improving the fire resistance of panels made of light gauge steel frames.

[0009] Therefore, it is an object of the invention to provide improved floor and wall panels, that are light in weight, provide sufficient strength for being used as load-bearing elements and that have a sufficient fire resistance. In particular, in the United Kingdom, for buildings over 30 meters height, at least 2 hours of fire resistance shall be achieved under the test standards laid down in the norm BS EN 1365-2: 2014. For buildings up to 18 meters, 60 minutes are required.

[0010] In order to solve these objectives, the invention provides a floor or wall panel comprising

- a frame made of profiled metal or timber sheet,
- joists made of profiled metal or timber sheet that connect opposite sides of the frame, wherein voids are present between the joists,
- a shield made of a metal or timber sheet spaced apart from a fire side of the joists, wherein a clearance is defined between a fire side of the joists and the shield,
- spacer elements arranged within the clearance between the joists and the shield, and
- a hardened mineral foam that fills the voids between the joists and that fills the clearance.

[0011] As used herein, the fire side of the panel refers to the side of the panel that is expected to be exposed to a fire. Therefore, the fire side of the joists refers to the side of the joist that faces towards the fire side of the panel.

[0012] The hardened mineral foam provides for an effective fire protection, wherein the mineral foam fills both, the voids between the joists and the clearance arranged between the fire side of the joists and the shield as defined by the spacer elements. In this way, the mineral foam that is arranged in the clearance functions as an insulation, i.e. it acts as an insulator preventing excessive heat from the fire side reaching the joists forming the structure.

[0013] Further, the mineral foam that is arranged between the joists functions as a heat sink to reduce the temperature build-up within the structural elements of the panel.

[0014] Further, the shield acts as a heat shield. The shield may also provide some structural contribution during fire by creating composite action.

[0015] The shield and the spacer elements act compositely with the fire side of joists to maintain the overall structural integrity of the joists, even with temperatures being above a critical point where structural integrity would otherwise be gone.

[0016] The hardened mineral foam does also provide support to the panel overall, even though it might be a weak material, by virtue of the fact that it is applying a small force over a large area.

[0017] Further, the spacer elements create a longer thermal path, again reducing the amount of excess heat reaching the base of the joists.

[0018] In combination, the shield, the spacer elements and the mineral foam within the clearance and the mineral foam between the joists act together to keep the temperature of the joists below the critical temperature required to maintain the structural integrity of the panel during fire.

[0019] In case of panels that are used for building external walls of a building, mineral foam is arranged to cover the fire side of the joists as well as the non-fire side opposite thereof.

[0020] Further, in case of panels that are used for building external walls of a building, the joists may be configured as studs. Thus, every reference in the instant disclosure to joists also includes studs.

[0021] Preferably, the mineral foam fills the entire volume of the voids between the joists and the entire volume of the clearance arranged between the fire side of the joists and the shield. An additional advantage here is that no voids are left within the panel, which removes the need to close cavities to prevent the spread of fire, smoke or hot gases via voids in the panel. In contrast prior art cassette panels, being hollow, potentially allow the passage of smoke and hot gases. Because of this risk, prior art cassette floors need to be closed around the edges with cavity barriers to prevent smoke spreading between fire compartments.

[0022] The hardened mineral foam is a lightweight construction element that has a relatively low density due to its pores or empty spaces, thereby adding minimal weight to the light gauge steel construction of the panel. The low mass of the hardened mineral foam also results in very significantly lower embodied CO_2.

[0023] Further, the hardened mineral foam is completely fire resistant due to its chemically inert property and therefore virtually non-combustible. Mineral foam also has a slow rate of heat transfer, which means that it acts as a fire shield, while maintaining its structural integrity despite exposure to intense heat.

[0024] Preferably, the hardened mineral foam has a density of 50-200 kg/m^3, preferably 75-175 kg/m^3.

[0025] The hardened mineral foam has excellent thermal properties, and in particular very low thermal conductivity. In particular, the thermal conductivity of the hardened mineral foam may be from 0.030 to 0.150 W/m.K, preferably from 0.030 to 0.060 W/m.K, more preferably from 0.030 to 0.055 W/m.K.

[0026] Preferably, the hardened mineral foam comprises a hydraulic binder, in particular Portland cement.

[0027] Hardened mineral foam may be produced by providing a slurry of cement, which is a mixture of a hydraulic binder and water, foaming the slurry of cement, i.e. introducing air bubbles into the slurry, and allowing the slurry of foamed cement to set and harden.

[0028] Preferably, the mineral foam may be produced by separately preparing a slurry of cement and an aqueous foam, contacting the slurry of cement with the aqueous foam to obtain the slurry of foamed cement and allowing the slurry of foamed cement to set and harden.

[0029] Methods for producing a mineral foam are described in WO 2013/150148 A1.

[0030] The shield that is arranged as a heat shield on the fire side of the panel preferably extends over the entire fire side surface of the panel. In order to enhance the stability of the panel, the shield may preferably be designed as a profiled sheet, preferably having a trapezoidal profile.

[0031] According to another preferred embodiment, the spacer elements may be longitudinal elements extending transverse, in particular perpendicular, to the span of the joists.

[0032] The longitudinal spacer elements may preferably be made of profiled sheet metal, in particular slotted sheet metal. When having a slotted design, the slots in the spacer elements act as interruptions in the thermal path towards the joists.

[0033] A sheathing board may preferably be fixed to the surface of the panel facing away from the fire side. The joists and the sheathing board act together to provide additional structural performance to the panel.

[0034] Tests have revealed that the panel of the invention does not require plasterboard for fire protection. Testing to a recognised standard (BS EN 1365-2: 2014) has shown that the panel of the invention achieves over 2 hours fire performance, without any reliance on plasterboard. When the test was stopped after the proscribed 2 hour period the floor was not exhibiting any signs of distress in terms of load-bearing capacity or rate of deflection, suggesting that a considerably longer performance was possible.

[0035] According to a further aspect of the invention, a method of producing a floor or wall panel is provided, comprising the steps of:

- providing a frame made of profiled metal or timber sheet, wherein joists made of profiled metal or timber sheet connect opposite sides of the frame with voids being formed between the joists,
- providing a shield made of a metal or timber sheet in a spaced apart relationship from a fire side of the joists, wherein a clearance is defined between a fire side of the joists and the shield, and spacer elements being arranged within the clearance between the joists and the shield, and
- filling the voids between the joists and filling the clearance with a slurry of foamed cement,

- allowing the slurry of foamed cement to set and harden.

[0036] Filling the voids and the clearance with the slurry of foamed cement is preferably performed by pouring the slurry into the cavities of the panel, so that the slurry fills all voids within the panel, thereby resulting in a panel that does not contain any unfilled spaces. The slurry of foamed cement typically has a good flowability during pouring that is compatible with small cavities due to the crossing of the different frame elements.
[0037] Preferably, the slurry of foamed cement is prepared by

(i) separately preparing a slurry of cement and an aqueous foam, wherein the cement slurry comprises water and Portland cement,
(ii) contacting the slurry of cement with the aqueous foam to obtain the slurry of foamed cement.

[0038] The generated aqueous foam has air bubbles with a D50, which is less than or equal to 400 μm, preferably from 100 to 400 μm, more preferably from 150 to 300 μm. Preferably, the generated aqueous foam has air bubbles with a D50 which is 250 μm.
[0039] In step (ii), the cement slurry may be homogenized with the aqueous foam by any means to obtain a slurry of foamed cement. Preferably, step (ii) of the process according to the invention may comprise the introduction of the cement slurry and the aqueous foam into a static mixer to obtain a slurry of foamed cement.
[0040] Portland cement as used for the production of the slurry of foamed cement may be any type of Portland cement, whatever its chemical composition is, and in particular whatever its alkaline content is. Therefore, one of the advantages is not having to select a specific type of Portland cement. Advantageously, the Portland cement used in the invention is selected from the cements readily available on the market.
[0041] The suitable cements used in step (i) of the invention are preferably the cements described according to the European NF EN 197-1 Standard of April 2012 or mixtures thereof, preferably cement of the types CEM I, CEM II, CEM III, CEM IV or CEM V.
[0042] According to a preferred embodiment of the invention, the Portland cement has a specific surface (Blaine) of 3000 - 10000 cm^2/g, preferably 3500 - 6000 cm^2/g.
[0043] The water/cement ratio (wt/wt ratio) of the cement slurry prepared in step (i) is preferably from 0.25 to 0.5, more preferably from 0.28 to 0.35, in particular 0.29. The water/cement ratio may vary, for example due to the water demand of the mineral particles when these are used. The water/cement ratio is defined as being the ratio by mass of the quantity of water (W) to the dry Portland cement mass (C) .
[0044] The cement slurry prepared in step (i) may comprise a water reducer, such as a plasticiser or a super-plasticiser. A water reducer makes it possible to reduce the amount of mixing water for a given workability by typically 10-15%. By way of example of water reducers, mention may be made of lignosulphonates, hydroxycarboxylic acids, carbohydrates, and other specific organic compounds, for example glycerol, polyvinyl alcohol, sodium alumino-methyl-siliconate, sulfanilic acid and casein as described in the Concrete Admixtures Handbook, Properties Science and Technology, V.S. Ramachandran, Noyes Publications, 1984.
[0045] By way of example of a super-plasticiser, the PCP super-plasticisers without an anti-foaming agent may be noted. The term "PCP" or "polyoxy polycarboxylate" is to be understood according to the present invention as a copolymer of acrylic acids or methacrylic acids and their esters of polyoxy ethylene (POE).
[0046] Preferably, the cement slurry comprises 0.05 to 1%, more preferably 0.05 to 0.5% of a water reducer, a plasticiser or a super-plasticiser, percentage expressed by mass relative to the dry cement mass.
[0047] Preferably, the cement slurry does not comprise an anti-foaming agent, or any agent having the property of destabilizing an air/liquid emulsion. Certain commercial super-plasticisers may contain anti-foaming agents and consequently these super-plasticisers are not preferred for the cement slurry used to produce the mineral foam according to the invention.
[0048] Preferably, the cement slurry used to produce the mineral foam comprises 0.05 to 2.5 wt.-% of an accelerator, expressed as dry mass relative to dry cement mass.
[0049] According to an embodiment, other additives may be added to the cement slurry or the aqueous foam. Such additives may be thickening agents, viscosifying agents, air entraining agents, setting retarders, coloured pigments, hollow glass beads, film forming agents, hydrophobic agents or de-polluting agents (for example zeolites or titanium dioxide), latex, organic or mineral fibres, mineral additions or their mixtures. Preferably, the additives do not comprise any defoaming agents.
[0050] The expression "thickening agent", is generally to be understood as any compound making it possible to maintain the heterogeneous physical phases in equilibrium or facilitate this equilibrium. The suitable thickening agents are preferably gums, cellulose or its derivatives, for example cellulose ethers or carboxy methyl cellulose, starch or its derivatives, gelatine, agar, carrageenan or bentonite clays.
[0051] According to an embodiment, the cement slurry used to produce the mineral foam may further comprise mineral

particles. Preferably, the cement slurry used to produce the mineral foam may comprise 0 to 50% of mineral particles, more preferably from 5 to 40%, most preferably from 5 to 35%, the percentages being expressed by mass relative to the mass of slurry of foamed cement.

[0052] The suitable mineral particles are selected from calcium carbonate, silica, ground glass, solid or hollow glass beads, glass granules, expanded glass powders, silica aerogels, silica fume, slags, ground sedimentary siliceous sands, fly ash or pozzolanic materials or mixtures thereof.

[0053] The invention will now be described in more detail by reference to exemplary embodiments shown in the figures, wherein:

- Fig. 1 shows a plan view of a wall panel of the invention,
- Fig. 2 shows a cross section along the line II-II of the panel of Fig. 1,
- Fig. 3 shows a detailed view of the cross section of Fig. 2,
- Fig. 4 shows a cross section along the line IV-IV of the panel of Fig. 1,
- Fig. 5 shows a detailed view of the cross section of Fig. 4,
- Fig. 6 shows a graph of the thermocouple temperatures versus time on the fire side of the joists, and
- Fig. 7 shows a graph of the thermocouple temperatures on the cool, non-fire side of the joists versus time.

[0054] Fig. 1 shows an exemplary floor or wall panel 1 in a plan view. The panel 1 comprises a rectangular frame 2 made of profiled sheet metal having two opposite short sides 3 and two opposite long sides 4. Further, joists 5 are provided that are made of profiled sheet metal and that connect opposite sides 3 of the frame 2. The joists 5 are fixed to the sides 3 of the frame 2 by suitable connection means, such as by welding, by riveting, by bolts or by screws. Due to the spaced apart relationship of the joists 5, voids 6 are each formed between adjoining joists 5 and between the joists and the sides 4 of the frame 2, said voids 6 extending over substantially the entire length 12 of the frame 2.

[0055] The voids 6 can also be seen in the cross-sectional view according to Fig. 2. Further, the voids 6 are filed with hardened mineral foam, i.e. the mineral foam fills the entire space that is present between adjoining joists 5 and between the joists 5 and the sides 4 of the frame 2.

[0056] In Fig. 2, the fire side of the panel 1 is depicted by arrow 7, which means that the panel 1 would be exposed to fire that is coming from the fire side according to arrow 7. On the fire side of the joists 5 a shield 8 is provided that is spaced apart from the joists 5, wherein a clearance 10 is defined between the fire side of the joists 5 and the shield 8. As will be seen later, spacer elements are arranged within the clearance 10 between the joists 5 and the shield 8. Further, a hardened mineral foam that fills the clearance 10 is provided. The shield 8 may be profiled, such as having a trapezoidal profile, as illustrated in Fig. 2. Further, a cover board 9 is shown in Fig. 2 that covers the non-fire side of the frame 2 and the joists 5.

[0057] As can be seen in more detail in the enlarged view according to Fig. 3, the joists 5 are each made of a C-shaped profile.

[0058] The spacer elements 11 may be seen in the cross-section view according to Fig. 4 as well as in the enlarged view according to Fig. 5. The spacer elements 11 are arranged within the clearance 10 between the joists 5 and the shield 8. The spacer elements 11, on one side thereof, are connected to the fire side of the joists 5 and, on the opposite side thereof, are connected to the shield 8. Welding, riveting, bolting or screwing may be used for connecting the spacer elements 11 to the joists 5 and the shield 8, respectively.

[0059] The composition of the mineral foam used for filing the voids and the clearance of the panels shown in Fig. 1 to 5 was produced from an aqueous foam and from a cement slurry as given in the following table.

Mix design for 1 m^3 of mineral foam				
Aqueous foam	Water (aqueous foam)	Tap water	42.7	kg/m^3
	Foaming agent	MapeAIR L/LA	1.067	kg/m^3
	Air		905.6	L/m^3
Cement slurry	Cement	Cookstown CEM II 42.5N (General Purpose)	80.6	kg/m^3
	Water (slurry)	Tap water	25.1	kg/m^3
	Superplasticiz er	85 wt.-% Dynamon NRG 1022 15 wt.-% Dynamon SW	0.343	kg/m^3
	Stabilizer	Floquat ASL diluted at 50%	2.877	kg/m^3
	Accelerator	ChrysoXel CBP	0.876	kg/m^3

[0060] MapeAIR L/LA is a foaming agent sold by Mapei.

[0061] Cookstown CEM II 42.5N (General Purpose) is a Portland cement produced at the Lafarge plant of Cookstone, in Ireland.

[0062] Dynamon NRG 1022 and Dynamon SW are two super-plasticizers sold by Mapei.

[0063] Floquat ASL is an aqueous solution of aluminium sulphate sold by SNF. It is here diluted at 50 wt.-%, in tap water.

[0064] The panel shown in Fig. 1-5 was subjected to a fire resistance test according to the specifications of the standard BS EN 1365 - 2:2014

[0065] Thermocouples were installed at several positions within the panel in order to measure the temperature of the joists on their fire side ("hot side") and on their side facing away of the fire side ("cold side").

Hot Side Temperature Analysis

[0066] Fig. 6 shows graphs of the thermocouple temperatures versus time on the fire side of the joists.

[0067] Within ~10 minutes all thermocouples on the hot side of the joists had reached ~100°C. The pure insulation effect of the hardened mineral foam is therefore not that large.

[0068] However, between 10 and 47 minutes, temperatures remained on a plateau of around 100°C, suggesting that there is a secondary insulation effect occurring.

[0069] This initial rise in temperature is correlated with the initial deflection of the shield, which reached an initial peak of 12mm after 12 minutes, with the deflection remaining constant until after 47 minutes.

[0070] The test observations note a release of steam at 47 minutes, which coincides with the point that temperatures start to rise significantly in TC233 and 231, followed by TC225, 226, 237. These thermocouples go onto reach higher temperatures by the end of the test (750 to 800°C).

[0071] In 3 other thermocouples, TC229, 235, 238, the plateau at ~100°C continues for a further 18 minutes, before a similar rate of temperature increase begins. The peak temperatures reached are also lower at <700°C.

[0072] The longer plateau effect and lower final temperatures are very probably linked to a differing build-up of mineral foam and steel sheet below these thermocouples.

[0073] The end joists, TC223, 241 are significantly cooler throughout all stages of the test.

Cool Side Temperature Analysis

[0074] Fig. 7 shows graphs of thermocouple temperatures on the cool, non-fire side of the joists versus time.

[0075] Temperatures remained at ambient levels of ~20°C, for 20 minutes. Temperatures then rise steadily in 6 thermocouples TC 222, 239, 227, 228, 224, 234, until they reach the 100°C plateau after ~45 minutes.

[0076] Three other thermocouples, TC230, 236, 240 take longer to reach the steady state plateau, but these are not linked to the delayed hot-side thermocouple positions.

Claims

1. A floor or wall panel comprising

   - a frame made of profiled metal or timber sheet,
   - joists made of profiled metal or timber sheet that connect opposite sides of the frame, wherein voids are present between the joists,
   - a shield made of a metal or timber sheet spaced apart from a fire side of the joists, wherein a clearance is defined between a fire side of the joists and the shield,
   - spacer elements arranged within the clearance between the joists and the shield, and
   - a hardened mineral foam that fills the voids between the joists and that fills the clearance and that optionally covers the fire side of the joists as well as the non-fire side opposite thereof.

2. A panel according to claim 1, wherein the shield is a profiled sheet, preferably having a trapezoidal profile.

3. A panel according to claim 1 or 2, wherein the hardened mineral foam has a density of 50-200 kg/m^3, preferably 75-175 kg/m^3.

4. A panel according to claim 1, 2 or 3, wherein the hardened mineral foam comprises a hydraulic binder, in particular Portland cement.

5. A panel according to any one of claims 1 to 4, wherein the spacer elements are longitudinal elements extending transverse, in particular perpendicular, to the span of the joists.

6. A panel according to any one of claims 1 to 5, wherein the longitudinal spacer elements are made of profiled sheet metal, in particular slotted sheet metal.

7. A method of producing a floor or wall panel, comprising the steps of:

- providing a frame made of profiled metal or timber sheet, wherein joists made of profiled metal or timber sheet connect opposite sides of the frame with voids being formed between the joists,
- providing a shield made of a metal or timber sheet in a spaced apart relationship from a fire side of the joists, wherein a clearance is defined between a fire side of the joists and the shield, and spacer elements being arranged within the clearance between the joists and the shield, and
- filling the voids between the joists and filling the clearance with a slurry of foamed cement, and optionally covering the fire side of the joists as well as the non-fire side opposite thereof with the slurry of foamed cement,
- allowing the slurry of foamed cement to set and harden.

8. A method according to claim 7, wherein the slurry of foamed cement is prepared by

(i) separately preparing a slurry of cement and an aqueous foam, wherein the cement slurry comprises water and Portland cement,
(ii) contacting the slurry of cement with the aqueous foam to obtain the slurry of foamed cement.

9. Wall or floor assembly for a building, comprising floor or wall panels according to any one of claims 1 to 6 that are connected with each other to form a floor or wall.

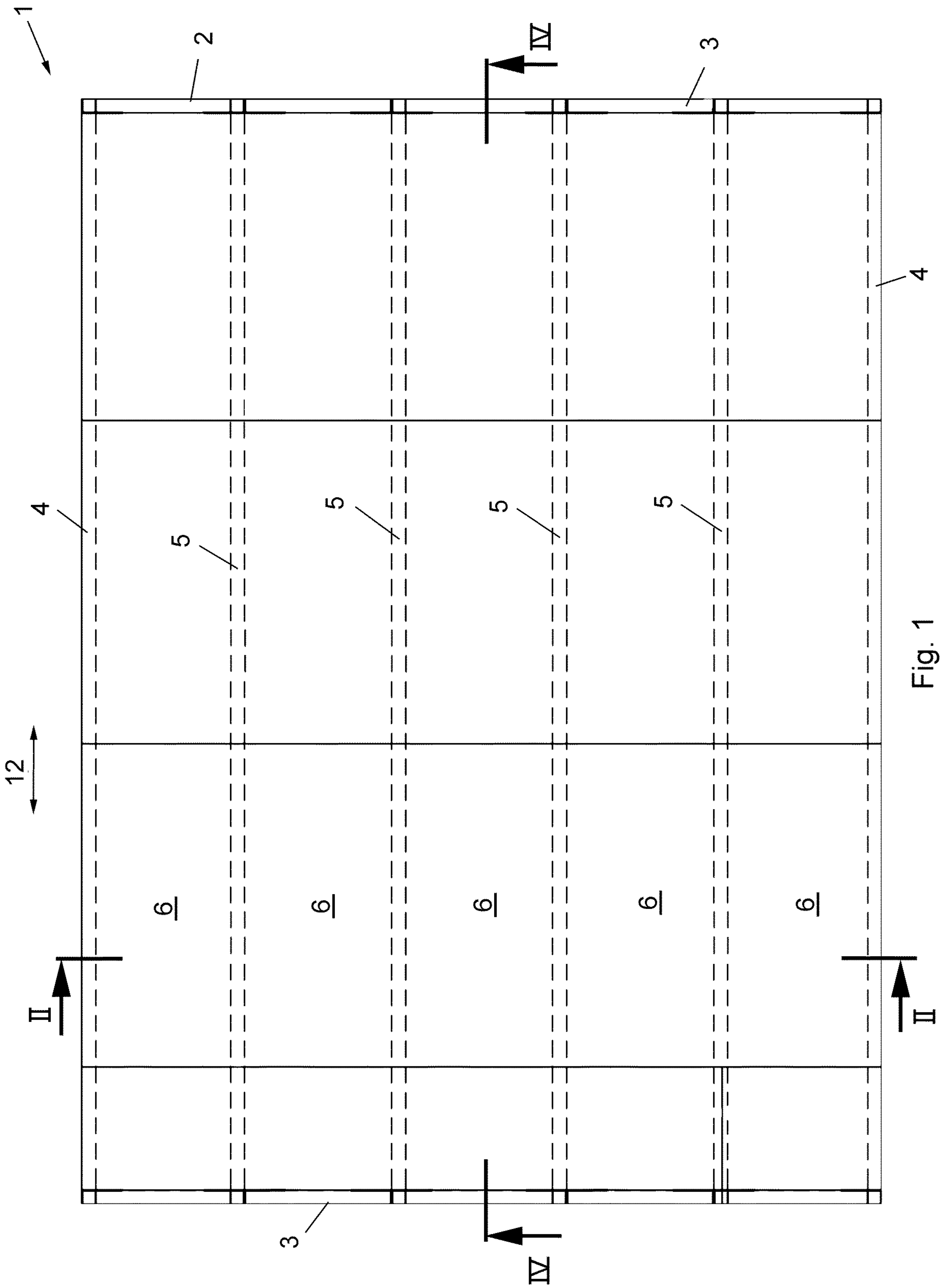


Fig. 1

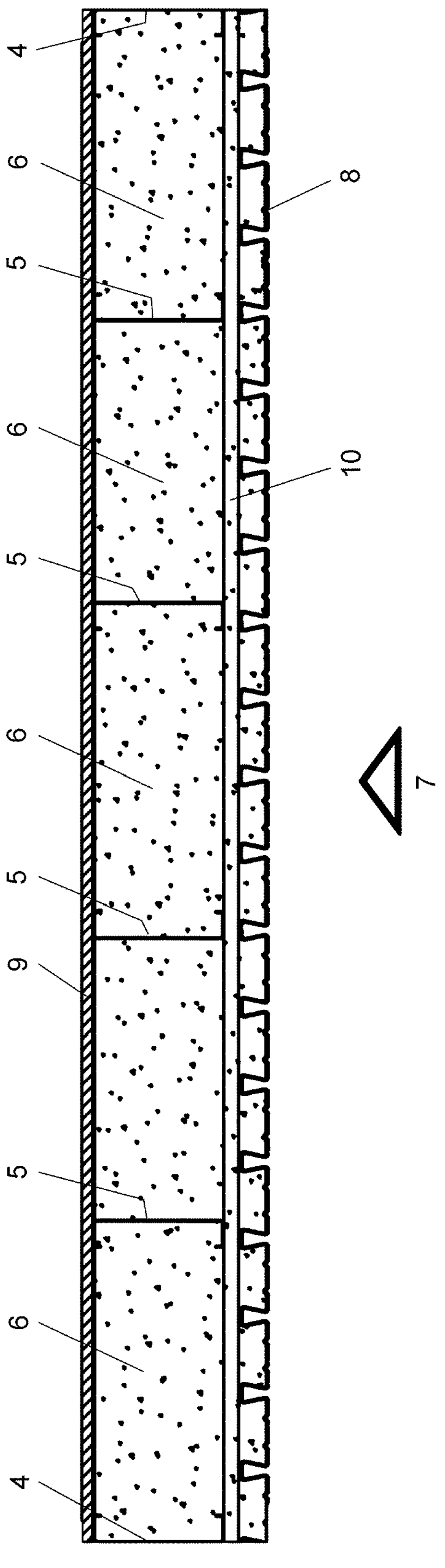


Fig. 2

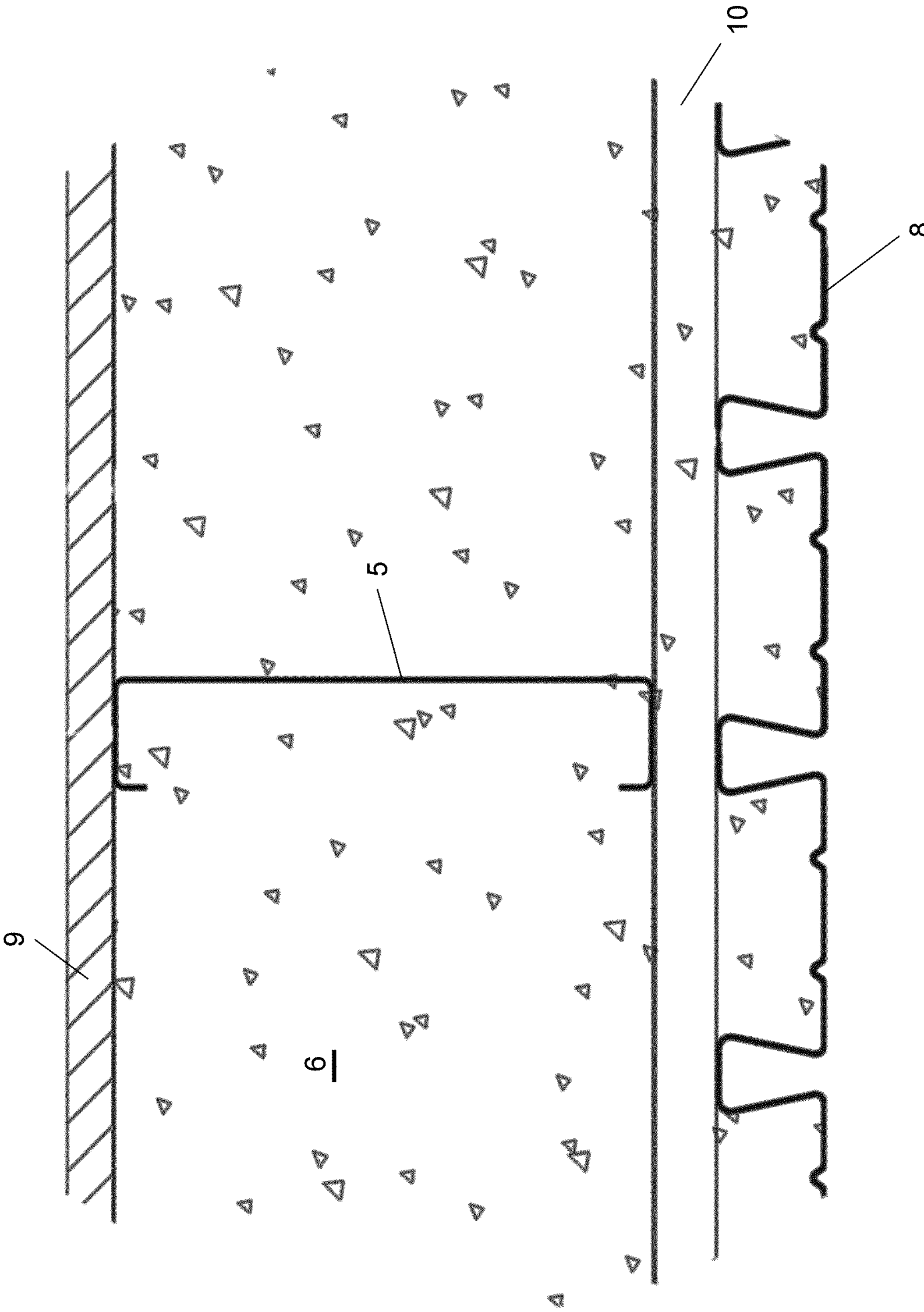


Fig. 3

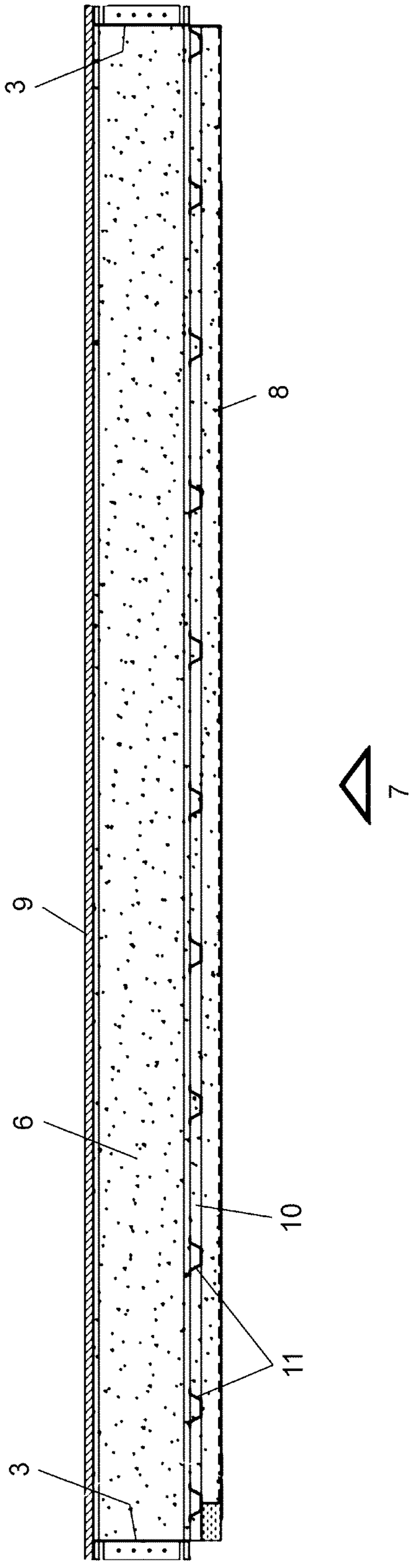


Fig. 4

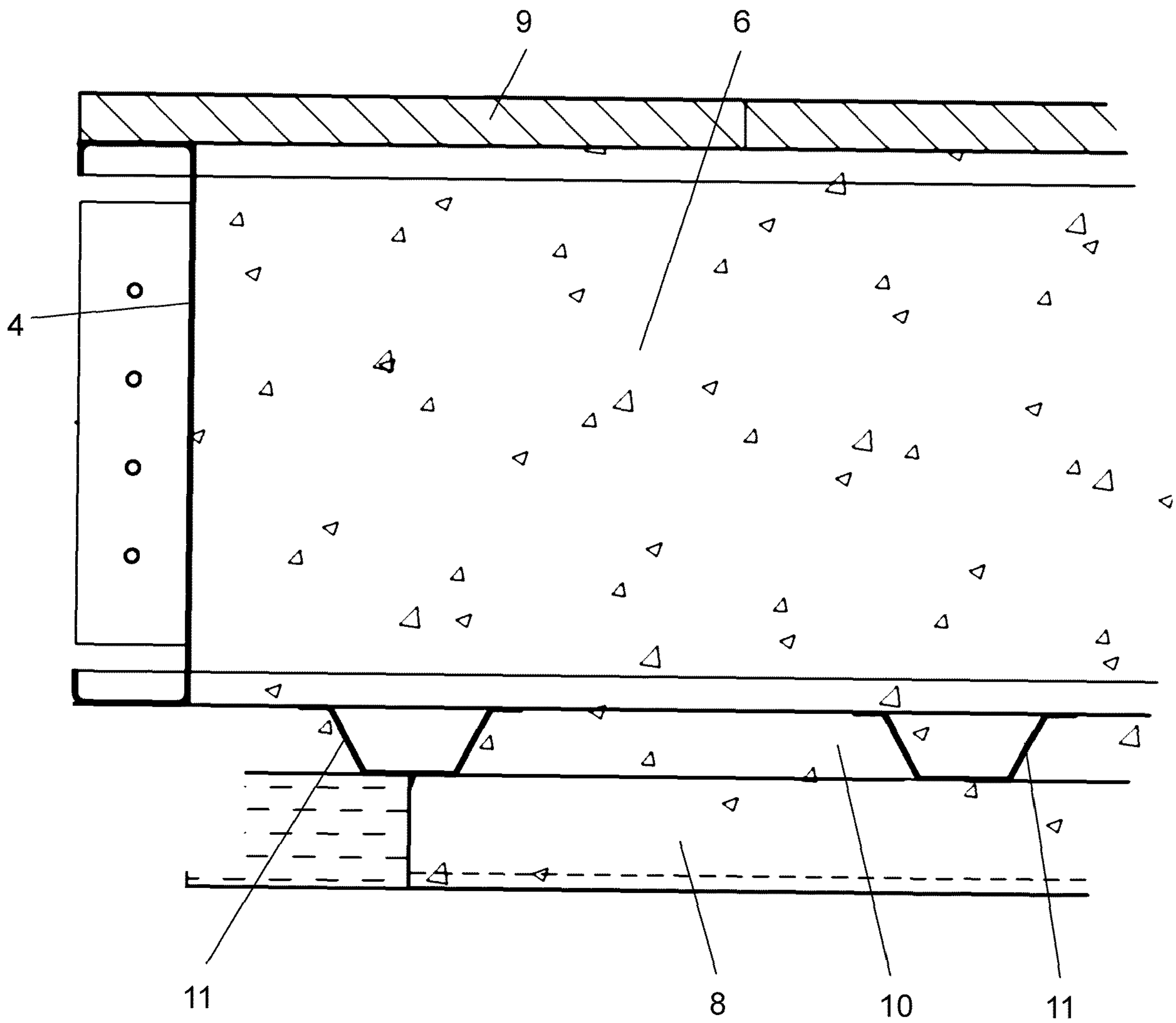
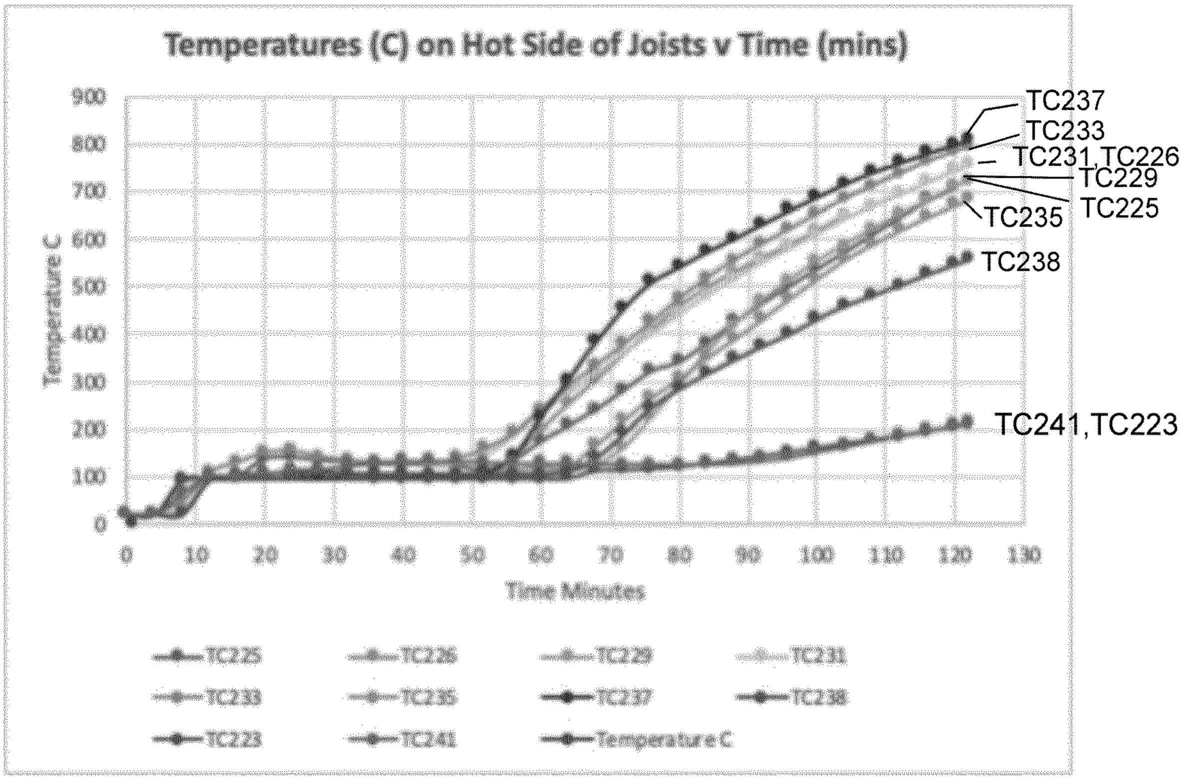


Fig. 5


Temperatures (C) on Hot Side of Joists v Time (mins)
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TC237
TC233
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TC238
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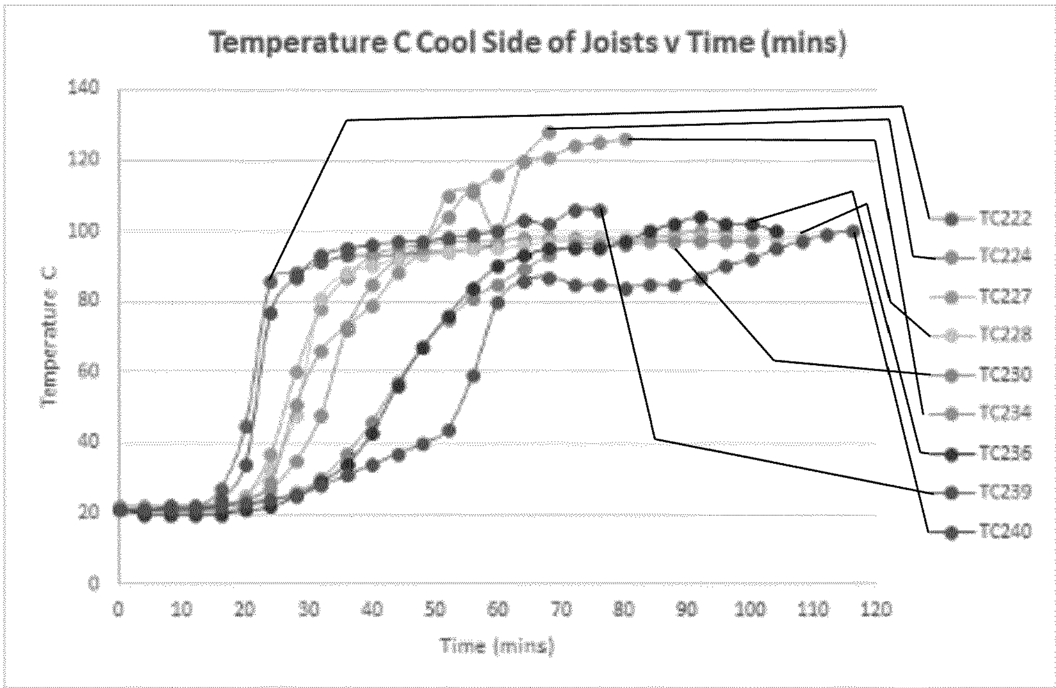
TC241
Temperature C

Fig. 6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Temperature C
Time (mins)
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50
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70
80
90
100
110
120
TC222
TC224
TC227
TC228
TC230
TC234
TC236
TC239
TC240

Fig. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 20 02 0534

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	WO 2016/033429 A1 (INNOVATIVE BUILDING TECHNOLOGIES LLC [US]) 3 March 2016 (2016-03-03) * paragraphs [0057], [0058], [0069] - [0071]; figures *	1-9	INV. E04B5/10 E04B5/12 E04C2/34
A	FR 2 038 057 A1 (ENTREPOSE) 8 January 1971 (1971-01-08) * the whole document *	1-9	
A	US 2011/047917 A1 (ROEN ROGER C [US]) 3 March 2011 (2011-03-03) * the whole document *	1-9	
			TECHNICAL FIELDS SEARCHED (IPC)
			E04B E04C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	17 March 2021	Stern, Claudio

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