

DESCRIPTION

TITLE: ADDITIVE MANUFACTURE OF AN INSULATING ELEMENT

5 [0001] The invention relates to the field of construction. It more particularly relates to the manufacture of insulating elements using an additive manufacturing technique.

[0002] In addition to its advantages in terms of comfort and savings, the
10 thermal insulation of buildings, both in construction and in renovation, is a crucial issue in combating global warming. It is therefore essential for construction elements to have the lowest possible thermal conductivity. To address this issue, a large number of technical solutions have been proposed that implement various insulating elements (mineral wools, organic foams,
15 etc.) associated with structural elements (walls, roofs, etc.).

[0003] The invention seeks to propose new techniques for manufacturing construction elements having improved thermal insulation.

20 [0004] Today, additive manufacturing techniques are experiencing promising developments in a large number of technical fields. Also called "3D printing," additive manufacturing is a method in which a computer-controlled robot manufactures three-dimensional objects by continuously depositing a material, layer upon layer. These techniques in particular allow the
25 manufacture of objects with complex shapes.

[0005] Additive manufacturing has for example been used to manufacture structural elements, such as concrete walls.

30 [0006] The additive manufacturing of construction elements, for example made from concrete or mortar, allows integration of the design, planning and construction processes as well as automation and streamlining thereof. Other

advantages of this technology are in particular reduced labor costs, reduced material losses and consumption, the elimination of formworks and reduced project times and investments. In the present text, concrete and mortar refer interchangeably to a material comprising a hydraulic binder and aggregates.

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[0007] In the known technologies, a wet mortar, obtained by mixing a dry mortar and mixing water, is pumped and conveyed toward a printing head secured to a robot or a gantry crane whose movement is controlled by computer. A layer of wet mortar is deposited on a layer of mortar previously deposited, generally by
10 being extruded through a nozzle. The printing head is moved continuously according to a predetermined diagram so as to manufacture the final object.

[0008] The invention proposes a different path for using this type of technique to obtain insulating construction elements.

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[0009] To this end, the invention relates to a method for obtaining an insulating element made from mineral foam by additive manufacturing, in which superimposed layers of a mineral foam paste are successively deposited, said mineral foam having, after hardening, a density of no more than 200 kg/m³.

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[0010] The invention also relates to a method for obtaining a construction element comprising at least one structural element and at least one insulating element made from mineral foam, said method comprising a step of obtaining said mineral foam insulating element using the method according to the invention.

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[0011] Another object of the invention is an insulating element made from mineral foam, or a construction element, able to be obtained using one of these methods.

[0012] The invention therefore applies the additive manufacturing techniques
30 not to build the structural or support element of the construction element, but on the contrary to build the insulating element. Printing the insulating element in particular makes it possible to benefit from the advantages of additive

manufacturing while complying, regarding the manufacture of the structural elements, with the certified and recognized conventional methods, which do not require special authorizations.

5 [0013] The construction element will most often be a wall or a wall element, in particular for a facade or interior load-bearing wall. It may also be a floor element. The element will generally be intended to be integrated into the structure of a building.

10 [0014] "Mineral foam" refers to a honeycomb or cellular mineral material. The voids or cells are preferably filled with air. The size of the voids or cells is preferably no more than 400 μm , in particular no more than 250 μm . The volume proportion of air in the foam is preferably between 10 and 80% (not taking into account the air comprised in any light porous aggregates
15 described in the remainder of the text).

[0015] The mineral foam preferably comprises at least one hydraulic binder.

[0016] Obtaining the mineral foam paste preferably comprises combining a
20 dry composition comprising at least one hydraulic binder with an aqueous solution, then mixing the mineral paste thus obtained.

[0017] Dry composition refers to a powdered mixture. After setting and hardening, the final foam may be called hardened foam, or cement foam,
25 mortar foam or concrete foam. The aqueous solution may simply be water, or water comprising, in solution, in dispersion or in suspension, one or several additives, in particular organic additives, for example surfactants, or mineral additives, for example silica nanoparticles.

30 [0018] The hydraulic binder is in particular chosen from Portland cements, high alumina cements, sulfoaluminate cements, hydrated lime, ground, granulated blast furnace slag, fly ash and mixtures thereof.

[0019] The mineral foam and/or the dry composition may also comprise aggregates, in particular light aggregates, that is to say, having an apparent density of less than 200 kg/m³. The light aggregates are in particular chosen from perlite, vermiculite, expanded glass beads, expanded polystyrene beads, cenospheres, expanded silicates, aerogels and mixtures thereof. The mineral foam may also comprise aggregates other than light aggregates, but preferably in a content by weight of no more than 20%, in particular no more than 15%, or even no more than 10% or no more than 5% (after hardening).

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[0020] The maximum size of the aggregates is preferably no more than 3 mm, in particular no more than 2 mm and even no more than 1 mm, given the reduced cross-section of the pumping device and of the nozzle of the printing head. To ensure good stability of the foam, the maximum size of the aggregates is even advantageously no more than 0.1 mm. The maximum size may be verified for example by screening.

[0021] The dry composition preferably comprises at least one additive, in particular chosen from superplasticizers, thickeners, accelerators and retarders. The dry mortar advantageously comprises inorganic thickeners, for example swelling clays, capable of increasing the elastic limit at rest of the wet mortar. The accelerators and retarders allow adjustment of the time necessary for setting and hardening of the hydraulic binder.

[0022] The mineral foam paste may be obtained by different techniques, which share the fact that a gas, in particular air, is introduced into the paste. The gas may in particular be generated or introduced during the mixing of the mineral paste, or contributed by an aqueous foam or by a solution containing a gas-generating agent, added to the paste after mixing.

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[0023] According to one embodiment, the dry composition and/or the aqueous solution comprises an air entraining agent capable of trapping air within the

mineral paste during mixing. In this case, the mineral foam paste is formed during the mixing. Such an agent is preferably a surfactant. It may in particular be an anionic surfactant. The anionic surfactant is advantageously chosen from alkylsulfates, alkylsulfonates, alkylethersulfates, alkylarylsulfates and surfactants developed from proteins or amino acids, for example N-acylglutamates and N-acylsarcosinates. The air entraining agent may also be polyvinyl alcohol.

[0024] In this embodiment, the dry composition preferably comprises at least 40%, or even at least 60% by weight of light aggregates, a hydraulic binder comprising a sulfoaluminate cement and/or a high alumina cement, an air entraining agent, in a content by weight of at least 0.3%, in particular of at least 0.5%, and optionally a viscosifying agent, in particular chosen from polyvinyl alcohols, starch ethers, cellulose ethers, guar ethers and clays. The light aggregates preferably have a mean diameter of no more than 80 μm .

[0025] According to another embodiment, the dry composition and/or the aqueous solution comprises a gas generator capable of generating gas bubbles within the mineral paste during mixing thereof. Such an agent is for example a metallic powder (for example aluminum, zinc, silicon, etc.) capable of reacting with the water and the hydroxides. It may also be a peroxide, for example hydrogen peroxide, for example capable of reacting with manganese salts.

[0026] Alternatively, the gas generator may be added to the mineral paste (after mixing). For example, obtaining the mineral foam paste may comprise a step of adding an aqueous solution containing this agent to the mixed paste. This addition may be done just before the printing head.

[0027] According to still another embodiment, obtaining the mineral foam paste further comprises a step of obtaining an aqueous foam, then a step of blending said aqueous foam with the mineral paste. In this case, the mineral foam is obtained by blending the mixed mineral paste and the aqueous foam. The aqueous foam is for example obtained by blending water and a foaming agent

(or a foam stabilizer), then introducing a gas, in particular air, by stirring, bubbling or pressurized injection. The median diameter of the bubbles of the aqueous foam is preferably no more than 400 μm , in particular no more than 250 μm .

- 5 [0028] The foaming agent is for example a surfactant. According to a preferred example, it is a surfactant derived from proteins or amino acids.

- [0029] For example, the mineral foam paste preferably comprises from 10 to 70% water; from 30 to 75%, in particular from 40 to 60%, cement, in particular
10 Portland cement; from 10 to 70%, in particular from 15 to 40%, fillers, in particular calcareous fillers, the median diameter of which (for a volume distribution) is no more than 5 μm , in particular between 1 and 4 μm ; up to 10%, in particular between 1 and 7%, fine particles whereof the median diameter is no more than 1 μm ; and optionally additives (water reducing
15 agents, plasticizers, superplasticizers, retarders or accelerators, thickeners, foaming agents, etc.). All of the indicated content levels are contents by weight. The blending of the aqueous foam with the mineral paste is preferably done using a static mixer, in particular of the helical type.

- 20 [0030] According to another example of this embodiment, the aqueous foam comprises mixing a cationic surfactant that is a quaternary ammonium salt (in particular a halide) and an anionic surfactant that is a C10-C24 carboxylic acid salt (in particular an alkali salt), for example potassium stearate. The hydraulic binder is then preferably Portland cement, in particular of type CEM I 52.5. The
25 mineral foam paste preferably comprises a latex, particularly chosen from vinyl and/or acrylic (co)polymers, for example styrene-acrylic copolymers.

- [0031] According to still another example of this embodiment, the aqueous foam comprises nanoparticles, in particular of silica, which have the property
30 of stabilizing the foams. Such foams are called "Pickering foams." The silica nanoparticles may in turn be stabilized by surfactants. The density of the mineral foam after hardening (in particular after 28 days) is preferably

between 40 and 200 kg/m³, in particular between 50 and 180 kg/m³, or even between 60 and 150 kg/m³, or between 80 and 120 kg/m³.

5 [0032] Due to the presence of a large quantity of gas, in particular of air, captured in a mineral matrix, the foam has a low thermal conductivity, in particular by reducing the heat transfers by convection and by conduction. The thermal conductivity of the mineral foam after hardening (in particular after 28 days) is preferably no more than 60 mW.m⁻¹.K⁻¹.

10 [0033] The method comprises successively depositing superimposed layers of mineral foam paste.

[0034] After the mineral foam paste is obtained, it is preferably pumped (in particular using a pump) and conveyed, generally in a pipe, toward the
15 printing head of a printer. The printing head in particular comprises a nozzle through which the paste is extruded. The extrusion nozzle is preferably located less than 100 mm from the underlying layer. The printer is for example an industrial robot or a gantry crane, bearing the printing head, and the movement of which is controlled by a computer. The computer in particular
20 comprises a recording medium on which a data set or a 3D model is stored as well as instructions, which, when executed by the computer, cause the latter to control the movement (trajectory, speed, etc.) of the printing head.

[0035] The printing speed is typically from 30 to 1000 mm/s, in particular from
25 50 to 300 mm/s. The thickness (or height, since here it involves the dimension in the vertical direction) of the layers of paste is preferably between 5 and 40 mm, in particular between 10 and 20 mm. The width of the layers of paste is preferably between 10 and 300 mm, in particular between 20 and 100 mm.

30 [0036] In the embodiment described above, comprising the blending of an aqueous foam and the mineral paste, this blending is preferably done using a static mixer. The aqueous foam is preferably added between the pump and the

printing head, ideally as close as possible to the printing head so as to preserve the structure of the foam. The quantity of aqueous foam relative to the quantity of mineral paste is preferably adjusted automatically, in particular based on the desired density. The ratio between the volume of aqueous foam added and the volume of mineral paste is preferably between 5 and 12. For example, for a density after hardening of 100 kg/m³, the ratio between the volume of aqueous foam added and the volume of mineral paste is typically about 10.

[0037] The method preferably comprises adding to the mineral foam paste, before deposition, a setting and/or hardening accelerator or a rheology modifier. The addition may in particular be done at or near the nozzle, therefore just before extrusion. Alternatively, the accelerator or the rheology modifier may be added immediately after deposition, on the surface of the layers. The setting accelerator is for example an aluminum sulfate or a lithium salt, depending on the type of hydraulic binder used. The rheology modifier for example allows the paste to be given a thixotropic nature. Adding a setting accelerator or a rheology modifier allows rapid consolidation of the mineral foam layers, such that they are able to bear the weight of the underlying layers without deformation.

[0038] The construction element comprising at least one structural element and at least one mineral foam insulating element may be obtained in different ways.

[0039] "Structural element" refers to an element of the building that fulfills a structural role or that participates in the reinforcement thereof. The structural element is for example a concrete wall.

[0040] According to one embodiment, the insulating element forms a formwork, the method further comprising a step for filling said formwork with a structural element, in particular made from concrete. As an example, the insulating element is printed so as to form two partitions facing one another and arranging a cavity, in which concrete is poured. The partitions may be planar or have extremely varied shapes, as allowed by the additive

manufacturing technique. A construction element is thus formed comprising a concrete partition surrounded by two outer insulating layers.

5 [0041] According to another embodiment, the mineral foam layers are deposited against at least one pre-existing structural element. The layers are thus deposited in contact with an element, for example made from concrete, along at least one of its main surfaces. A concrete wall is for example obtained having an insulating layer on at least one (optionally on two) of its surfaces.

10 [0042] In the context of this embodiment, the mineral foam layers may be deposited between and in contact with two pre-existing structural elements. A wall is thus formed for example comprising a first and a second concrete partition between which a layer of mineral foam is arranged.

15 [0043] The construction elements may be prefabricated elements, intended to be assembled on the construction work site, for example using a mortar, so as to form the exterior or interior walls (for example, the interior load-bearing walls) of the building. The elements may also be manufactured directly on the construction work site and form the complete wall of the building.

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Claims

1. A method for obtaining an insulating element made from mineral foam by additive manufacturing, wherein superimposed layers of a mineral foam
5 paste are successively deposited, said mineral foam having, after hardening, a density of no more than 200 kg/m³.
2. The method according to claim 1, wherein the mineral foam comprises at least one hydraulic binder, in particular chosen from Portland cements,
10 high alumina cements, sulfoaluminate cements, hydrated lime, ground, granulated blast furnace slag, fly ash and mixtures thereof.
3. The method according to the preceding claim, wherein obtaining the mineral foam paste comprises combining a dry composition comprising at
15 least one hydraulic binder with an aqueous solution, then mixing the mineral paste thus obtained.
4. The method according to the preceding claim, wherein the dry composition and/or the aqueous solution comprises an air entraining agent
20 capable of trapping air within the mineral paste during mixing.
5. The method according to claim 3, wherein the dry composition and/or the aqueous solution comprises a gas generator capable of generating gas
bubbles within the mineral paste during mixing thereof.
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6. The method according to claim 3, wherein obtaining the mineral foam paste further comprises a step of obtaining an aqueous foam, then a step of blending said aqueous foam with the mineral paste.
- 30 7. The method according to one of the preceding claims, wherein the size of the voids of the mineral foam is no more than 400 µm, in particular no more than 250 µm.

8. The method according to one of the preceding claims, wherein the density of the mineral foam after hardening is between 50 and 180 kg/m³, in particular between 60 and 150 kg/m³.

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9. The method according to one of the preceding claims, wherein the mineral foam and/or the dry composition comprises light aggregates, in particular chosen from perlite, vermiculite, expanded glass beads, expanded polystyrene beads, cenospheres, expanded silicates, aerogels and mixtures thereof.

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10. The method according to the preceding claim, wherein the maximum size of the aggregates is at most 1 mm, in particular at most 0.1 mm.

11. A method for obtaining a construction element comprising at least one structural element and at least one insulating element made from mineral foam, said method comprising a step of obtaining said mineral foam insulating element using the method according to one of the preceding claims.

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12. The method according to claim 11, wherein the construction element is a wall or a wall element.

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13. The method according to one of claims 11 or 12, wherein the insulating element forms a formwork, said method further comprising a step for filling said formwork with a structural element, in particular made from concrete.

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14. The method according to one of claims 11 or 12, wherein the mineral foam layers are deposited against at least one pre-existing structural element.

15. The method according to the preceding claim, wherein the mineral foam layers are deposited between and in contact with two pre-existing structural elements.

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