

DESCRIPTION

TITLE: ADDITIVE MANUFACTURING OF INSULATING CONSTRUCTION ELEMENTS

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

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[0002] In addition to its advantages in terms of comfort and savings, the 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, etc.) associated with structural elements (walls, roofs, etc.).

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

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[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 manufacture of objects with complex shapes.

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

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[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 trench boxes and reduced project times and investments.

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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
10 deposited, generally by 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 is proposed for obtaining by this type of technique
15 construction elements having a thermal insulation function.

[0009] To that end, an object of the invention is a method for obtaining, by additive manufacturing, a construction element comprising at least one structural element and at least one insulating element, wherein a dry mortar is
20 mixed with mixing water so as to form a basic wet mortar, the basic wet mortar is transported to a printing head, and stacked layers of mortar are successively deposited by moving the printing head so as to form the at least one structural element and the at least one insulating element, said method being such that, before depositing the layers of mortar belonging to an insulating element, an
25 aqueous foam is additionally added to said basic wet mortar during the transport of said basic wet mortar to the printing head.

[0010] Another object of the invention is a construction element comprising at least one structural element and at least one insulating element, obtained, or
30 simply capable of being obtained, by the method according to the invention.

[0011] Another object of the invention is a system for implementing the method according to the invention. Such a system comprises a mixing device capable of mixing a dry mortar with the mixing water so as to form a basic wet mortar, a transport device capable of transporting said basic wet mortar to a printer
5 comprising a printing head able to be moved so as to deposit stacked layers of mortar, a foam generating device capable of generating an aqueous foam, and a mixing device capable of mixing said basic wet mortar and said aqueous foam.

10 [0012] "Structural element" refers to an element of the building that fulfills a structural role or that contributes to the reinforcement thereof. As regards the insulating element, it adds thermal and even sound insulation.

[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
15 element. The element will generally be intended to be integrated into the structure of a building. Indeed, the presence of the structural element enables the construction element to play this structural role.

20 [0014] In the case of a wall, the construction element preferably has, in a vertical plane when in use (that is, once the element is incorporated into the building), a height and a width and, along a perpendicular to this vertical plane, a thickness. Typically, each structural element and each insulating element extends in the vertical plane over the full height and width of the construction
25 element. These elements then succeed one another in the thickness of the construction element. The structural and insulating elements are preferably in contact with one another, so that the thickness of the wall is equal to the sum of the thicknesses of each of these elements. The construction element may be rectangular parallelepiped in shape. However, other shapes are possible,
30 since the additive manufacturing technique enables a wide variety of shapes to be obtained.

[0015] The invention therefore applies the additive manufacturing techniques to build both the structural or support element(s) of the construction element as well as at least one insulating element.

5 [0016] The invention makes it possible, starting from the same dry mortar, to adjust the density of the final mortar in order to build with the same printing system, and particularly with the same printing head, the structural element(s) and the insulating element(s).

10 [0017] Thus, when the printing head deposits layers of mortar belonging to a structural element, aqueous foam is normally not added. The wet mortar arriving at the printing head is then the basic wet mortar. However, when the printing head is depositing layers of mortar belonging to an insulating element, a certain quantity of aqueous foam is first added to the basic wet mortar, which
15 makes it possible to adjust the density of the final mortar and consequently to provide thermal insulation properties to the element. The wet mortar arriving at the printing head is then a mixture of the basic wet mortar and the aqueous foam.

20 [0018] The, or each, structural element is normally obtained without adding aqueous foam. Thus, particularly dense layers of mortar are obtained, capable of playing their structural role. Preferably, the density after hardening (particularly after 28 days) of the layers of mortar belonging to the structural element is at least 2000 kg/m^3 , particularly at least 2100 kg/m^3 . This density is
25 preferably less than or equal to 2500 kg/m^3 .

[0019] At least one, or even each, insulating element is obtained with addition of aqueous foam. Thus, layers of mortar are obtained that are less dense than the layers of mortar belonging to the structural element. The density after
30 hardening (particularly after 28 days) of the layers of mortar belonging to at least one insulating element is preferably at most 1500 kg/m^3 , particularly at most 1200 kg/m^3 .

[0020] According to one embodiment, the construction element comprises an insulating element the density whereof, after hardening (particularly after 28 days), is at most 100 kg/m³. Such an element will have excellent thermal insulation properties.

[0021] According to another embodiment, the construction element comprises an insulating element the density whereof, after hardening (particularly after 28 days), is between 700 and 1500 kg/m³, particularly between 800 and 1200 kg/m³. Such an element will have moderate thermal insulation properties.

[0022] A preferred embodiment combines both of the preceding embodiments. In this case, the construction element comprises a structural element, a first insulating element and a second insulating element, the second insulating element having a density greater than that of the first insulating element. In the method, the quantity of aqueous foam added to the basic wet mortar when the first insulating element is obtained is then greater than the quantity of aqueous foam added to the basic wet mortar when the second insulating element is obtained. Preferably, the density after hardening of the mortar layers belonging to the first insulating element is at most 100 kg/m³ and the density after hardening of the mortar layers belonging to the second insulating element is between 700 and 1500 kg/m³. In the case of a wall, the construction element preferably comprises, from the exterior of the wall, the support element, then the first insulating element, then the second insulating element.

[0023] In an alternative to this preferred embodiment, only the second insulating element is obtained by additive manufacturing. As regards the first insulating element, it is obtained by pouring the constituent material into the cavity formed by the structural element and the second insulating element. The pouring step may be carried out by means of a robot.

[0024] According to one embodiment of the invention, the structural and insulating elements are formed sequentially. The mortar transport device then advantageously comprises a single hose transporting the wet mortar to a single printing head, which will print each element (structural or insulating) one after the other. Thus, the system preferably comprises a single pump and a single hose, the aqueous foam being added during the formation of the insulating elements and stopped during the formation of the structural elements.

[0025] According to another embodiment of the invention, the structural and insulating elements are formed simultaneously. The mortar transport device then advantageously comprises a plurality of hoses each transporting wet mortar to a different printing head, or to a different chamber of the same printing head, the aqueous foam only being added in the hose(s) transporting the basic wet mortar intended to form an insulating element. Each hose may be connected to the same pump or to a different pump.

[0026] Dry mortar refers to a powdered mixture. The dry mortar preferably comprises at least one mineral binder, preferably hydraulic, for example chosen from Portland cements, aluminous cements, sulfoaluminate cements, hydrated lime, ground, granulated blast furnace slag, fly ash and mixtures thereof. The hydraulic binder is advantageously Portland cement, or even consists of such a cement. The mineral binder may also be gypsum based or be a geopolymer binder.

[0027] The dry mortar preferably comprises aggregates. These aggregates are, in particular, siliceous, calcareous and/or dolomite aggregates. It may also include 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 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. The maximum size may be verified for example by screening.

- 5 [0028] The dry mortar preferably comprises at least one additive, in particular chosen from superplasticizers, thickeners, accelerators and retarders. The dry mortar advantageously comprises inorganic thickeners, for example bloating 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
10 and hardening of the hydraulic binder.

- [0029] The composition of the dry mortar is preferably adjusted in such a way that the basic wet mortar has a thixotropic behavior. Preferably, the viscosity of the basic wet mortar increases by a factor of at least 50 only one second
15 after the wet mortar has left the printing nozzle. The basic wet mortar then has a low viscosity for higher shear rate so that it may easily be pumped and carried, but has an immediate increase in its structural stability as soon as it leaves the nozzle of the printing head, thus enabling it to support the overlying layers before setting and hardening. This deposition on a layer of mortar that
20 is still wet enables the adhesion to be improved between the successive layers, and thus the final mechanical strength of the construction element.

- [0030] The dry mortar is mixed with the mixing water in order to form the basic wet mortar. The mixing water may simply be water, or water comprising, in
25 solution, in dispersion or in suspension, one or more additives, in particular organic additives, for example surfactants.

- [0031] The mixing ratio, that is, the ratio between the amount of mixing water and the amount of dry mortar (by weight) may be adjusted if necessary
30 according to the nature of the element. Alternatively, the mixing ratio may be the same for all the elements. The mixing ratio is preferably at most 0.5, particularly between 0.05 and 0.20.

[0032] The wet mortar has a pasty consistency and can be pumped and transported to the printing head. Pumping may be carried out, for example, by means of a screw pump. Transport is typically carried out in a hose. The transport device therefore preferably comprises a pump, particularly a screw pump, as well as at least one hose.

[0033] At least for producing insulating elements, an aqueous foam is added to the basic wet mortar during transport of the basic wet mortar to the printing head.

[0034] The mixing of the aqueous foam and the basic wet mortar is preferably done using a static mixer. The mixing device is therefore preferably a static mixer.

[0035] 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. Adding it too close to the printing head, however, may be detrimental to a homogenous mixture of the aqueous foam with the basic mortar.

[0036] The quantity of aqueous foam relative to the quantity of basic wet mortar is preferably adjusted automatically. In particular, it is adjusted based on the desired density in the area in question. The ratio between the volume of aqueous foam added and the volume of basic wet mortar is preferably between 0.5 and 15, particularly between 1 and 12.

[0037] For example, for a density after hardening of 100 kg/m^3 , the ratio between the volume of aqueous foam added and the volume of basic wet mortar is typically about 10. For a density after hardening of 800 kg/m^3 , the ratio between the volume of aqueous foam added and the volume of basic wet mortar is typically about 1.3.

[0038] 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 at most 400 μm , in particular at most 200 μm .

[0039] The foaming agent is for example a surfactant. According to a preferred example, it is a surfactant derived from proteins or amino acids.

[0040] According to another example, 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.

[0041] According to still another example, the aqueous foam comprises nanoparticles, in particular of silica, which have the property of stabilizing the foams. Such foams are called "Pickering foams." The silica nanoparticles may in turn be stabilized by surfactants.

[0042] Due to the addition of aqueous foam, the mortar comprises a large quantity of gas, in particular of air, captured in a mineral matrix, and consequently has a low thermal conductivity, in particular by reducing the heat transfers by convection and by conduction. The thermal conductivity of the insulating elements after hardening (in particular after 28 days) is preferably at most 60 $\text{mW}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$. It is ideally around 40 $\text{mW}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$.

[0043] The printing head comprises in particular a nozzle through which the wet mortar (basic wet mortar, possibly with aqueous foam added) 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 particularly comprises a recording medium wherein is stored a set of data or 3D model as well as instructions, which when executed by the computer guide it to control the movement (trajectory, speed, etc.) of the printing head as well as other parameters of the method, for example the ratio between the quantity of aqueous foam and the quantity of basic wet mortar, or the mixing ratio (that is, the ratio between the quantity of mixing water and the quantity of dry mortar).

[0044] The printing speed is typically from 30 to 1000 mm/s, in particular from 50 to 300 mm/s. The thickness (or height, since here it involves the dimension in the vertical direction) of the layers of mortar is preferably between 5 and 40 mm, in particular between 10 and 20 mm. The width of the layers of mortar is preferably between 10 and 300 mm, in particular between 20 and 100 mm.

[0045] The method also may comprise adding to the wet mortar, 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 mortar to be given a thixotropic nature. Adding a setting accelerator or a rheology modifier allows rapid consolidation of the mortar layers, such that they are able to bear the weight of the overlying layers without deformation.

[0046] The construction element may also comprise reinforcing parts. These parts, intended to mechanically reinforce the elements, or preferably deposited during the printing of the mortar layers. They may be deposited horizontally in the thickness of a mortar layer, or vertically, and then extend into several layers of mortar. The reinforcing parts are for example made of steel.

[0047] 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.

[0048] The lateral dimensions of the construction element are preferably between 1 and 4 m, particularly between 1 and 3 m. The thickness is preferably at most 70 cm, particularly between 20 and 50 cm.

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[0049] The thermal resistance of the construction element is preferably between 3.0 and 5.0 m².K/W.

[0050] [Fig. 1] shows one particular and non-limiting embodiment of the invention.

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[0051] [Fig. 2] schematically shows an example of a system according to the invention

[0052] Figure 1 schematically represents a top view of a construction element 1, in this instance a wall, obtained by the method of the invention.

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[0053] The wall 1 here is in the form of a rectangular parallelepiped having a thickness e and a width L . This is only an example here, and it goes without saying that the additive manufacturing technique allows a wide variety of forms.

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[0054] The wall 1 comprises, from the exterior of the building in use, a structural element 2 in contact with a first insulating element 3, which itself is in contact with a second insulator 4. Each of these elements extend over the full height and width of the wall.

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[0055] The densities after 28 days of hardening are more than 2000 kg/m³ for the structural element 2, less than 100 kg/m³ for the first insulating element 3, and between 700 and 1200 kg/m³ for the second insulating element 4. The second insulating element 4 is therefore more in the form of a lighter wall, the first insulating element 3 being more in the form of a mineral foam.

[0056] Such wall 1 was obtained by means of a printing system 20, schematically depicted in figure 2, comprising:

- a mixing device 22 for mixing the dry mortar with the mixing water,
- 10 - a transport device comprising a screw pump 24 facilitating the pumping and transporting of the basic wet mortar thus obtained in a hose 25,
- a foam generating device 26 facilitating the generation of an aqueous foam, the foam being inserted into the hose 25 after the pump 24
- a mixing device 27, more particularly a static mixer connected to the hose 25
- 15 in order to mix the basic mortar with the aqueous foam,
- a printing head 28 comprising a nozzle through which the wet mortar can be extruded in order to deposit a layer of wet mortar 11 on previously deposited layers of mortar 12. The movement of the printing head 28 was carried by a computer-controlled robot.

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[0057] The dry mortar comprised Portland cement and siliceous type fine aggregates. The mixing ratio was 0.12 to obtain the basic wet mortar.

[0058] The structural and insulating elements were formed sequentially. The structural element 2 was first formed by superimposing layers of mortar 12 the width whereof was equal to the thickness of the layer. During this manufacturing, no aqueous foam was added to the basic wet mortar. In a second step, the second insulating element was formed separated from the structural element, so as to create a cavity. During this manufacturing, aqueous

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30 foam was added to the basic wet mortar, the ratio between the volume of aqueous foam and the basic wet mortar being about 1.3. In a third step, the first insulating element was poured into the cavity.

[0059] Alternatively, the first insulating element was produced by additive manufacturing, like the structural element and the second insulating element.

Claims

1. A method for obtaining, by additive manufacturing, a construction element (1) comprising at least one structural element (2) and at least one
5 insulating element (3, 4), wherein a dry mortar is mixed with mixing water so as to form a basic wet mortar, said basic wet mortar is transported to a printing head (28), and stacked layers of mortar (11, 12) are successively deposited by moving said printing head (28) so as to form said at least one structural element (2) and said at least one insulating element (3, 4), said method being
10 such that, before depositing the layers of mortar belonging to an insulating element (3, 4), an aqueous foam is additionally added to said basic wet mortar during the transport of said basic wet mortar to the printing head (28).
2. The method according to claim 1, wherein the construction element (1)
15 is a wall or a wall element.
3. The method according to one of the preceding claims, wherein the density after hardening of the layers of mortar belonging to the structural element (2) is at least 2000 kg/m^3 , particularly at least 2100 kg/m^3 .
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4. The method according to one of the preceding claims, wherein the density after hardening of the layers of mortar belonging to the at least one insulating element (3, 4) is at most 1500 kg/m^3 .
- 25 5. The method according to claim 4, such that the construction element (1) comprises an insulating element (3) the density whereof after hardening is at most 100 kg/m^3 .
6. The method according to claim 4, such that the construction element
30 (1) comprises an insulating element (4) the density whereof after hardening is between 700 and 1500 kg/m^3 , particularly between 800 and 1200 kg/m^3 .

7. The method according to one of the preceding claims, wherein the construction element (1) comprises a structural element (2), a first insulating element (3) and a second insulating element (4), the second insulating element (4) having a density greater than that of the first insulating element (3), the quantity of aqueous foam added to the basic wet mortar when the first insulating element (3) is obtained being greater than the quantity of aqueous foam added to the basic wet mortar when the second insulating element (4) is obtained.
8. The method according to the preceding claim, wherein the density after hardening of the mortar layers belonging to the first insulating element (3) is at most 100 kg/m^3 and the density after hardening of the mortar layers belonging to the second insulating element (4) is between 700 and 1500 kg/m^3 .
9. The method according to one of the preceding claims, wherein the structural elements (2) and the insulating elements (3, 4) are formed sequentially.
10. The method according to one of claims 1 to 8, wherein the structural elements (2) and the insulating elements (3, 4) are formed simultaneously.
11. The method according to one of the preceding claims, wherein the quantity of aqueous foam relative to the quantity of basic wet mortar is adjusted automatically.
12. The method according to one of the preceding claims, wherein the dry mortar comprises at least one hydraulic binder, in particular chosen from Portland cements, aluminous cements, sulfoaluminate cements, hydrated lime, ground granulated blast furnace slag, fly ash and mixtures thereof.
13. The method according to one of the preceding claims, wherein the

mixing of the aqueous foam and the basic wet mortar is done using a static mixer (27).

14. A construction element (1) comprising at least one structural element
5 (2) and at least one insulating element (3, 4), capable of being obtained by the method according to one of the preceding claims.

15. A system for implementing the method according to one of claims 1 to
10 13, comprising a printer comprising a printing head (28) that can be moved so as to deposit stacked layers of mortar (11, 12), a mixing device (22) capable of mixing a dry mortar with mixing water so as to form a basic wet mortar, a transport device (24, 25) capable of transporting said basic wet mortar to said printer, a foam generating device (26) capable of generating an aqueous foam,
15 and a mixing device (27) capable of mixing said basic wet mortar and said aqueous foam.