

Description

Title : Method and device for manufacturing an anisotropic fibrous concrete

TECHNICAL FIELD

The present invention pertains to a method and to a device for manufacturing anisotropic fibrous concrete.

PRIOR ART

5 Fibrous concretes, that is to say mortars of cement or clay reinforced by means of metal, plant, mineral or synthetic fibres, are known from the prior art.

 As is known *per se*, the addition of little or very slightly oriented fibres to the mortar makes it possible to confer on the final concrete improved mechanical properties (quasi isotropic), notably better resistance to shear and fissuring stresses.

10 As is also known, a mortar may also be reinforced more locally by elongated and oriented elements, steel or composite bars, wires, yarns, which makes it possible to confer on the manufactured concrete element better resistance to tensile stresses while giving ductility to the whole since the element does not break after the first fissure due to tensile stresses.

15 The present invention aims to provide a method and a device for manufacturing an anisotropic fibrous concrete material having improved mechanical characteristics compared to those of the prior art.

DESCRIPTION OF THE INVENTION

20 This aim of the invention is attained with a device for additive manufacturing by extrusion of anisotropic fibrous concrete, comprising a multi-axis robot having a head bearing an extrusion assembly including an extrusion nozzle for extruding a bead of mortar jointly with continuous fibres oriented along the longitudinal direction of this bead.

25 Thanks to these characteristics, it is possible to orient the continuous fibres along a favoured direction inside the mortar and to obtain an optimal arrangement

of these fibres, conferring anisotropy on the final bead of concrete enabling better resistance notably to tensile stresses of this bead.

It is possible to obtain, thanks to this principle of continuous extrusion of a bead, a concrete having an important level of fibres along the longitudinal direction of the bead, typically from 5 to 10 % or even more in a section perpendicular to this direction, compared to the order of 3% maximum for a fibrous concrete of the prior art, obtained by mixing, stirring, of fibres in a batch of mortar before moulding or extrusion, and thus without really favoured orientation: the fibres are more or less randomly oriented. Above these 3%, the mixture is more difficult to work (ball of fibres, jamming of systems).

The fact of introducing continuous fibres of several tens of microns diameter, which will be differentiated here from yarns in general millimetric, and in large number, enables the elaboration of a material profoundly different to what exists conventionally. Such a fibres/matrix assembly enables a mechanical operation similar to that of conventional composite materials, carbon/epoxy for example, in the sense that the bi-material may be considered homogeneous at a certain scale, which signifies identical mechanical behaviour at all points of the section of the bead.

This is effectively the case because the quasi-homogeneous distribution of a large number of fibres in the paste enables optimal distribution of stresses, the fibres taking up the tensile stresses and the matrix ensuring by shear the correct distribution.

This is not the case for beads reinforced with elements of greater section and in small number (bars or yarns) which have more a reinforced structure behaviour than a material behaviour.

Thus, this better distribution enables better distributed microfissuring, thus avoiding important macrofissures in the direction perpendicular to the cord on in the hardened state. It also enables a very different hold of the bead during the process (rheology, in the fresh state), because the mortar “holds up” much better thanks to the fibres, which is very interesting for deposition by additive manufacturing methods (without mould) for example.

Small diameter fibres are also easier to drive along by the paste during extrusion because the ratio between their contact surface with the paste and their

mass/rigidity is favourable. It will thus be possible to avoid more easily the motorisation rapidly necessary to drive wires or thick yarns.

Finally, using small diameter fibres, thus having low flexural rigidity, confers on the bead better workability in the sense that it is possible to bend it more during deposition for example via an additive method.

The invention also relates to a device thus defined, wherein the extrusion assembly comprises a mortar mixer situated upstream of the extrusion nozzle.

The invention also relates to a device thus defined, wherein said extrusion assembly comprises a constriction area situated between said mixer and said extrusion nozzle.

The invention also relates to a device thus defined, wherein the extrusion assembly comprises means for injecting into the mortar a setting accelerator additive.

The invention also relates to a device thus defined, comprising an injection head situated between the mixer and the constriction area for injecting the setting accelerator additive.

The invention also relates to a device thus defined, wherein said extrusion nozzle comprises radial bridges provided with orifices for introducing said fibres.

The invention also relates to a device thus defined, wherein said extrusion nozzle comprises peripheral orifices for introducing said fibres.

The invention also relates to a device thus defined, comprising a magazine of coils on which are wound said fibres, and members for guiding said fibres from said coils to said extrusion nozzle.

The invention also relates to an installation comprising a device thus defined, and a system for supplying and pumping said mortar to said mixer.

The invention also relates to an additive manufacturing method implementing a device thus defined, wherein it is the adherence of the fibres with the mortar that drives these fibres into the bead.

The invention also relates to an additive manufacturing method implementing a device thus defined, wherein said fibres are subjected to a surface treatment and/or to a mechanical treatment before extrusion with said mortar.

The invention also relates to an additive manufacturing method implementing a device thus defined, wherein flexurally flexible fibres are used which are introduced into the heart of said mortar.

5 The invention also relates to an additive manufacturing method implementing a device thus defined, wherein flexurally rigid fibres are used which are introduced into the periphery of said mortar.

The invention also relates to an additive manufacturing method implementing a device thus defined, wherein said fibres are chosen from the group comprising fibres made of carbon, metal, glass, basalt, polymer, unitary or stranded.

10 The invention also relates to an additive manufacturing method implementing a device thus defined, wherein the injection of the setting accelerator additive causes an at least sixfold multiplication of the shear threshold of the mortar between the region for injecting the setting accelerator additive and the end of the nozzle.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Other characteristics and advantages of the present invention will become clear on reading the description that follows, and by examining the appended figures, in which:

Figure 1 is an overall perspective view of an installation according to the invention;

20 Figure 2 is an axial sectional view of an embodiment of an extrusion assembly according to the invention;

Figure 3 is a side view of the extrusion nozzle of the assembly of figure 2;

Figure 4 is a perspective view of this nozzle;

25 Figure 5 is a transversal sectional view of this nozzle, taken along the sectional plane V-V of figure 4;

Figure 6 is a view analogous to that of figure 2, with a mixture of mortar and fibres in the course of extrusion;

Figure 7 is a transversal sectional view of the bead of concrete extruded by the extrusion assembly of figure 2;

Figure 8 is an axial sectional view of another embodiment of an extrusion assembly according to the invention;

Figure 9 is a side view of the extrusion nozzle of the assembly of figure 8;

Figure 10 is a perspective view of this nozzle;

5 Figure 11 is a transversal sectional view of this nozzle, taken along the plane of section XI-XI of figure 9;

Figure 12 is a view analogous to that of figure 8, with a mixture of mortar and fibres in the course of extrusion; and

10 Figure 13 is a transversal sectional view of the bead of concrete extruded by the extrusion assembly of figure 8;

Figure 14 is a general view showing the addition of accelerator into the extrusion assembly.

DETAILED DESCRIPTION OF PARTICULAR EMBODIMENTS

15 In all of these figures, identical or analogous references designate identical or analogous members or sets of members.

Reference will now be made to figure 1, in which an installation for manufacturing a fibrous concrete according to the invention is represented.

As may be seen in this figure, this installation comprises a robot 1 such as a commercially available 6-axis robot, manufactured for example by the ABB Company.

20 On the head 3 of this robot is mounted a device according to the present invention. This device comprises an extrusion assembly 5 supplied on the one hand by a mortar pump 7 and on the other hand by continuous fibres 9 coming from coils 11 installed on a magazine 13, and guided by a plurality of yarn-guides 15a, 15b, 15c.

25 The continuous fibres may be for example made of carbon, metal, glass, basalt, polymer, or an association of these various materials. They are small diameter fibres, that is to say of the order of magnitude of a micron rather than a millimetre (except for metal yarn which can reach 100 microns). These fibres are in general available assembled into yarns grouping together several thousands of fibres and constituting a yarn having a diameter of the order of magnitude of a millimetre.

The coils 11 may be rotationally driven by the traction of the fibres 9 alone, or instead be rotationally assisted by motorisation means.

Reference will now be made to figure 2, in which a first embodiment of an extrusion assembly 5 of the device according to the invention is represented.

5 In this figure, the direction of circulation of the mortar and the fibres is indicated by the arrow F: the terms “upstream” and “downstream” will be understood hereafter with respect to the direction of this arrow.

This first embodiment is quite particularly suitable for fibres 9 having a relative rigidity, that is to say a relatively important resistance to flexural stresses. These
10 sufficiently rigid fibres can hold up and penetrate well while spreading out in the section of the bead, including in the central area. Another device for such more flexible fibres is described hereafter and is the subject of figures 8 to 13.

The extrusion assembly 5 comprises, in its upstream part, a mortar mixer 17 of substantially cylindrical shape inside of which a mixing impeller 19 can turn under the
15 action of a motor (not represented). This mixer is extended, in its downstream part, by a constriction area 21 of substantially conical shape.

This constriction area 21 is itself extended, in its downstream part, by an extrusion nozzle 23 of which the lower part is substantially cylindrical, of diameter less than that of the mixer 17.

20 As is visible in figures 2, 3, 4, and 5, in its upstream part, this extrusion nozzle 23 has a peripheral swelling 25 provided with peripheral through orifices 27 distributed in a regular manner, both circumferentially and axially.

As is visible in figure 6, these peripheral orifices 27 are provided to receive the fibres 9 represented in figure 1, coming from the coils 11 arranged on the magazine 13.

25 The operating mode of the installation according to the invention results directly from the description that precedes.

This installation makes it possible to manufacture a bead of anisotropic fibrous concrete, which comes out of the nozzle 23 by extrusion.

The robot 1 conveys the end 29 of the extrusion nozzle 23 to the area where it is wished to deposit the bead of fibrous concrete: this may be for example on an area where it is wished to manufacture a concrete wall by additive printing, that is to say by superposition of beads of fibrous concrete.

5 A mortar (for example a mixture of cement or clay with aggregates) is then introduced into the mortar pump 7, in such a way as to send it into the mixer 17 of the extrusion assembly 5, where it is then kneaded by the impeller 19.

 If necessary, different adjuvants are incorporated in this mortar, in the mixer 17, making it possible to modify the physical and/or chemical characteristics thereof,
10 with a view notably to ensuring its perfect compatibility and adherence with the fibres 9.

 The parameters (time, speed, etc.) of mixing the mortar in the mixer 17 are adapted to the rheological characteristics, that is to say *in fine* with the desired viscosity and the shear threshold.

 The mortar is next pushed by the impeller 19 into the constriction area
15 21, where it hence undergoes shear stresses contributing to the good homogeneity of the mixture.

 When the mortar next arrives in the nozzle 23, it encounters the fibres 9 coming from the coils 11, and guided by the yarn guides 15a, 15b, 15c up to the inside of the peripheral orifices 27.

20 Advantageously, these fibres, which may consist of single fibres of small diameter (i.e. of the order of magnitude of a micron), yarns, wires or strands of yarns or wires, will have been able to undergo, during their manufacture or instead between their uncoiling from the coils 11 and their arrival in the peripheral orifices 27, different physical-chemical treatments (surface attack, pre-impregnation, etc.) or mechanical treatments
25 (tensioning, taking up play, etc.) aiming to optimise the adherence of these fibres with the mortar.

 In so doing, the mortar, drives along and incorporates these fibres 9 while circulating inside the extrusion nozzle 23; the characteristics of this nozzle (length, inner diameter) are determined in such a way as to enable the mortar to reach a shear threshold

(i.e. force required to cause the mortar to flow) which is sufficient to cancel out the relative speed of the mortar with respect to the fibres.

It should be understood that it is only the adherence of the mortar to the fibres 9 which makes it possible to drive them along with the movement of the mortar.

5 At the outlet of the end 29 of the nozzle 23, it is then possible to obtain a bead of fibrous concrete of which the typical transversal section is represented in figure 7: in this first embodiment, the fibres 9 are distributed in a substantially homogeneous manner over the whole section of the matrix 31 formed by the mortar, which solidifies at the end of a certain time.

10 Typically, this method for extruding continuous fibres 9 with the mortar makes it possible to obtain, in section, from 5 to 10% or even more of fibres 9 aligned in the axis of the bead with respect to the matrix 31, unlike isotropic fibrous concretes of the prior art, with which it is difficult to exceed 3% of fibres more or less randomly distributed in all directions: it is thus possible to speak of a greater density of aligned fibres compared
15 to concretes of the prior art, and thus of anisotropic mortar since the bead will indeed have a different mechanical behaviour and with better performance in the direction of the bead than in the transversal direction.

 In theory, a much greater density of fibres could even be obtained, the only physical limit being that the inter-fibre distances cannot be less than the largest
20 aggregates contained in the mortar that it would be necessary to choose the smallest possible if it is wished to increase this density.

 It may be noted that the different parameters brought into play, such as for example the time and the speed of mixing of the mortar in the mixer 17, the geometry of the constriction area 21, the density and the geometric distribution of the peripheral
25 orifices 27, the diameter and the length of the nozzle 23, the characteristics and quantities of adjuvants of the mortar, the nature of the fibres 9 and the characteristics of the treatments that are applied thereto, etc., are a function of the physical-chemical characteristics (notably rheology) that it is wished to obtain for the bead of concrete at the outlet of the extrusion nozzle 23.

It will be noted that the ratio between the section of the extrusion nozzle 23 and the cumulative sections of the fibres 9 characterises the density of fibres that it is wished to obtain inside the matrix 31.

Figures 8 to 13 represent another embodiment of extrusion assembly 5 of the device according to the invention, suitable for relatively flexible fibres, that is to say having a relatively low flexural resistance.

In this other embodiment, the orifices 21 for introducing the fibres 9 are distributed on radial bridges 33, making it possible to distribute these fibres radially between the periphery of the extrusion nozzle 23 and the centre thereof, and thus obtain in the matrix of mortar 31 visible in figure 13, a "ray of sunlight" arrangement of these fibres. This device enables better guiding of the fibres than that described in relation with figures 4 to 6 intended for more rigid fibres. This distribution of the orifices on the radial bridges 33 makes it possible to help the flexible fibres penetrate into the heart of the bead of mortar (which passes through the remaining empty spaces which appear in the form of white triangles situated between the radial bridges 33 in figure 11), and to avoid them being pushed out into the periphery by the flow of mortar (which would happen with a device represented in figures 4 to 10.

As may be understood in light of the preceding, the present invention makes it possible to obtain a bead of fibrous concrete provided with perfectly distributed longitudinal fibres, thus having physical-chemical characteristics that are adjustable to order before the setting of the mortar, depending on the use that it is wished to make of this bead.

Once the mortar has solidified, a bead of anisotropic fibrous concrete is obtained of which the resistance to different stresses (notably tensile stresses) is considerably better than that obtained with fibrous concretes of the prior art, and which behaves in the manner of a composite material comprising a matrix and a particular geometric arrangement of fibres.

It is possible in particular to limit considerably the risk of fissuring of this anisotropic fibrous concrete.

As illustrated in figure 14, a setting accelerator additive 34 is added to the mortar 31 in the extrusion assembly 5 before deposition of this mortar through the end 29, to ensure that the deposited bead of mortar 31 sets rapidly after its deposition on a support 36, this support 36 being able to be a bead of mortar deposited beforehand.

5 In these conditions, the mortar deposited by the nozzle 23 on mortar deposited beforehand by this same nozzle is thus supported by the mortar which has already set, thanks to the addition of accelerator, which makes it possible to carry out an additive printing cycle with a suitable rapidity.

10 The addition of the additive 34 makes it possible to generate at the level of the end 29 a bead of mortar sufficiently flexible or liquid so that it can be slightly crushed or pressed onto the support 36 which extends roughly perpendicularly to the orientation of the nozzle 23, this support 36 itself being able to be a layer deposited beforehand by 3D printing.

15 This low consistency during deposition allows more or less any angle between the nozzle and the support and avoids curved deposits having resort to a degree of additional rotation of the nozzle around its axis. Such an additional rotation would be necessary if the bead came out of the end 29 with a high consistency while consequently having a complementary shape defined by the shape of the nozzle. Without addition of additive at the level of the head 39, the material would have to have from outlet of the mixer 17 a high consistency to make it possible to stack the layers, which would not enable
20 crushing during deposition.

 As is visible in figure 14, the nozzle 23 has an orientation approximately perpendicular to the support 36, and it is displaced parallel thereto, in accordance with the 3D printing process. The fact that the nozzle 23 generates a flexible material makes it
25 possible to ensure a suitable deposition of the bead, and the fact that it contains the additive 34 ensures that it sets sufficiently fast to constitute a rigid support forming a stable seating for receiving another bead of mortar.

 In other words, thanks to the addition of additive, it is possible to use a mortar that is very flexible or liquid at the moment when it comes out of the nozzle 23,
30 while having the assurance that this mortar will set rapidly after its deposition.

In practice, the additive 34 is added as late as possible to the mortar to enable this mortar both to be flexible when it comes out of the nozzle and to set rapidly after having been deposited.

In this respect, and as is illustrated in figure 14, the additive 34 is added
5 to the mortar 31 directly in the extrusion assembly 5. The additive 34 is contained in a recipient 37 being able to be borne by the assembly 5, and it is injected into the mortar 31 downstream of the mixer 17 and upstream of the constriction area 21. In practice, the additive 34 is conveyed from its recipient 37 to the mortar 31 via a duct 38 of which the end situated in the mortar 31 is equipped with an injection head 39 ensuring the diffusion
10 of the additive in the flow of mortar 31 that comes from the mixer 17 and which is engaged in the constriction 21.

The fact of arranging at the level of the injection head 39 a relatively fluid mortar 31 makes it possible to better impregnate the fibres 9 which are introduced just after. This constitutes an important condition for the mechanical operation of the
15 anisotropic concrete, the impregnation being all the more efficient when the mortar is liquid.

The fact of using a mortar of which the viscosity increases rapidly after having passed the injection head 39, thanks to the addition of the accelerator, ensures an important shear between the mortar and the fibres so that the flow of mortar 31 drives
20 with it the fibres 9, which makes it possible to unwind the coils without resorting to an external device.

In practice, when it arrives at the level of the injection head 39, the mortar has a viscosity characterised by a shear threshold approximatively equal to 100Pa, and this viscosity increases up to a shear threshold comprised approximately between 600Pa and
25 1000Pa at the level of the end 29 of the nozzle 23, in the case of a nozzle having for example a length of 10 cm. The shear threshold value at the level of the end 29 may be decreased if the nozzle 23 is longer, the drive length of the fibres by the mortar then being greater.

More generally, the nature of the mortar, the acceleration additive, and the flow rate of mortar are advantageously adjusted so that the shear threshold is

multiplied at least sixfold between the area for injecting the additive and the end 29 of the nozzle 23.

Claims

1. Device for additive manufacturing by extrusion of anisotropic fibrous concrete, comprising a multi-axis robot (1) having a head (3) bearing an extrusion assembly (5) including an extrusion nozzle (23) for extruding a bead of mortar (31) jointly with continuous fibres (9) oriented along the longitudinal direction of this bead.
5
2. Device according to claim 1, wherein the extrusion assembly (5) comprises a mortar mixer (17) situated upstream of the extrusion nozzle (23).
- 10 3. Device according to claim 2, wherein said extrusion assembly (5) comprises a constriction area (21) situated between said mixer (17) and said extrusion nozzle (23).
- 15 4. Device according to claim 1, wherein the extrusion assembly (5) comprises means for injecting into the mortar (31) a setting accelerator additive (34).
- 20 5. Device according to claims 3 and 4, comprising an injection head (39) situated between the mixer (17) and the constriction area (21) for injecting the setting accelerator additive (34).
6. Device according to claim 1, wherein said extrusion nozzle (23) comprises radial bridges (33) provided with orifices (27) for introducing said fibres (9).
7. Device according to claim 1, wherein said extrusion nozzle (23) comprises peripheral orifices (27) for introducing said fibres (9).
25
8. Device according to claim 1, comprising a magazine (13) of coils (11) on which said fibres (9) are wound, and members for guiding (15a, 15b, 15c) said fibres (9) from said coils (11) to said extrusion nozzle (23).

9. Installation comprising a device according to claim 2, and a system for supplying and pumping (7) said mortar (31) to said mixer (17).

5 10. Additive manufacturing method implementing a device according to claim 1, wherein it is the adherence of the fibres (9) with the mortar (31) that drives these fibres into the bead.

10 11. Additive manufacturing method implementing a device according to claim 1, wherein said fibres (9) are subjected to a surface treatment and/or to a mechanical treatment before extrusion with said mortar (31).

15 12. Additive manufacturing method implementing a device according to claim 1, wherein flexurally flexible fibres (9) are used that are introduced into the heart of said mortar (31).

20 13. Additive manufacturing method implementing a device according to claim 1, wherein flexurally rigid fibres (9) are used that are introduced into the periphery of said mortar (31).

 14. Additive manufacturing method implementing a device according to claim 1, wherein said fibres (9) are chosen from the group comprising fibres made of carbon, metal, glass, basalt, polymer, unitary or stranded.

25 15. Method implementing a device according to claim 3, wherein the injection of the setting accelerator additive (39) causes an at least sixfold multiplication of the shear threshold of the mortar (31) between the region of injection of the setting accelerator additive (39) and the end (29) of the nozzle (23).