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(54) **REINFORCED THREE-DIMENSIONAL OBJECTS PRODUCED BY ADDITIVE MANUFACTURING AND RELEVANT METHOD**

(57) A method for producing a reinforced three-dimensional object from a binder composition with an additive manufacturing process, comprising the steps of:
a) Applying a first curable binder composition in the setting state with an additive manufacturing device, especially having a movable printing head, to produce the three-dimensional object (UP);
b) During and/or after producing the three-dimensional object (UP), forming at least one cavity (C) for receiving a reinforcement element (RB) in the three-dimensional object (UP);
c) Insertion of a reinforcing element (RB) into the at least one cavity (C);
d) Casting of the reinforcing element (RB) inside the at least one cavity (C) with a second curable binder composition (SL) in the setting state which is chemically and/or physically different from the first curable binder composition.

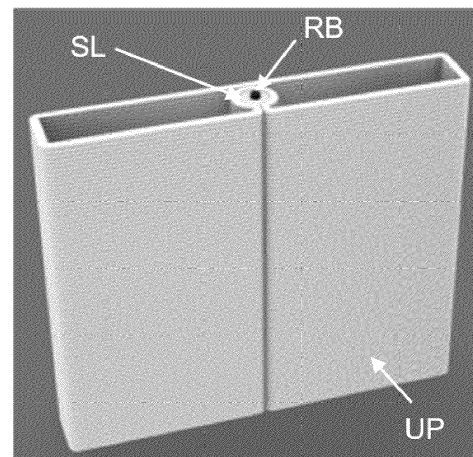


Fig. 4

Description

Technical field

[0001] The invention relates to a method for producing a reinforced three-dimensional object from binder compositions with an additive manufacturing process and a reinforced three-dimensional object.

Background art

[0002] In construction industry, curable binder compositions, such as e.g. mineral binder compositions, are widely used for various applications. Examples of such compositions are resin, mortar, concrete, grout, or screed compositions.

[0003] Attempts have been made for some time to produce geometrically demanding construction elements using additive manufacturing processes. The term "additive manufacturing process" or "additive production" refers to processes in which a spatial object or a molded body is produced by the targeted spatial deposition, application and/or solidification of material.

[0004] The deposition, application and/or consolidation of the material, e.g. the curable binder composition, is carried out in particular on the basis of a data model of the object to be generated and in particular layer-by-layer. Thus, in the additive manufacturing process, each object is typically produced from one or more layers. Usually, a formless material (e.g. liquids, powders, granulates, etc.) and/or a form-neutral material (e.g. tapes, wires) is used to manufacture an object, which is subjected in particular to chemical and/or physical processes (e.g. melting, polymerizing, sintering, curing). Additive manufacturing processes are also referred to as "generative manufacturing processes" or "3D printing", among others.

[0005] Additive manufacturing in the construction sector is quickly developing and projects involving this technology are becoming more and more ambitious.

[0006] However, producing structural elements from cementitious materials, such as mortars or concrete, by additive manufacturing is a highly demanding task. While cementitious materials are known for their high compressive strength, they have a rather low tensile and flexural strength. Therefore, structural elements made from these materials usually need to be reinforced, e.g. with steel rebars or fibers providing flexural strength.

[0007] Unlike traditional casting methods, with additive manufacturing it is hardly possible to install the reinforcement element, e.g. steel rebars, before producing the object by additive manufacturing. This is because robots or gantry printers will hardly be able to navigate safely around complex reinforcement structures.

[0008] In order to circumvent these problems, WO 2015/034438 A1 (ETH; Sika Technology AG), proposes a method of fabricating a 3-dimensional structure comprising the steps of: providing a mesh formwork element

such that a cavity bound by at least two opposing portions of the mesh formwork is formed; accumulating a material in the cavity; and allowing the material to harden; wherein apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of the accumulated material or vice versa such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

[0009] Although this approach represents a suitable solution to produce complex structures which would hardly be obtainable by traditional casting techniques, the production of the reinforcing formwork element is rather complex.

[0010] Thus, there is still a need for new and improved solutions that overcome the aforementioned disadvantages as far as possible.

Disclosure of the invention

[0011] It is an object of the present invention to provide improved solutions for producing reinforced three-dimensional objects from binder compositions, especially mineral binder compositions, with an additive manufacturing process. In particular, the solution should allow for producing three-dimensional objects that are as light as possible while having tensile and flexural strengths as high as possible.

[0012] Surprisingly, it was found that these objects can be achieved with the method according to independent claim 1.

[0013] Specifically, according to the invention, a method for producing a reinforced three-dimensional object from a binder composition with an additive manufacturing process comprises the steps of:

a) Applying a first curable binder composition, especially a mineral binder composition, with an additive manufacturing device, especially having a movable printing head, to produce the three-dimensional object;

b) During and/or after producing the three-dimensional object, forming at least one cavity for receiving a reinforcement element in the three-dimensional object;

c) Insertion of a reinforcing element into the at least one cavity;

d) Casting of the reinforcing element inside the at least one cavity with a second curable binder composition which is chemically and/or physically different from the first curable binder composition.

[0014] As it turned out, the inventive concept allows for producing reinforced three-dimensional objects by additive manufacturing in a highly efficient manner. Es-

pecially, since the reinforcing element(s) are inserted into the cavities of the three-dimension object after production, there is no need to apply the curable binder composition around preinstalled reinforcements, which would hinder deposition of the curable binder material. In contrast, the additive manufacturing process can be performed essentially similar to a process of producing a three-dimensional object without reinforcement.

[0015] Since the additive manufacturing allows for producing objects with highly complicated structures, it is possible to specifically design the three-dimensional object with at least one or more cavities for receiving the reinforcing element at an optimal position for reinforcing the object. Thereby the weight impact of the reinforcing elements can be minimized while the strength of the objects is maximized.

[0016] Furthermore, casting of the reinforcing element inside the at least one cavity with a second curable binder composition allows for establishing a highly reliable bonding between the reinforcing element and the first curable binder composition forming the three-dimensional object. Thereby, the second curable binder composition can be optimized in terms of flowability and/or bonding properties such that the cavity around the reinforcing element is completely filled, resulting in a perfectly embedded and securely bonded reinforcing element. Thus, compatibility problems can be avoided.

[0017] Due to the decoupling of the production of the three-dimensional object and the installation of the reinforcing element, it is furthermore possible to use the additive manufacturing device, or components thereof, such as e.g. a mixing unit, for producing the second curable binder composition after having produced the three-dimensional object and/or for performing the casting of the reinforcing element with the second curable binder composition inside the at least one cavity.

[0018] In addition, the inventive method can be performed with known equipment used in additive manufacturing or 3D printing, respectively. Thus, there is no need to provide additional devices.

[0019] Further aspects are described below and are subject of the further independent claims. Particularly preferred embodiments are outlined throughout the description and the dependent claims.

Ways of carrying out the invention

[0020] A first aspect of the present invention is directed to a method for producing a reinforced three-dimensional object from a binder composition with an additive manufacturing process comprises the steps of:

- a) Applying a first curable binder composition with an additive manufacturing device, especially having a movable printing head, to produce the three-dimensional object;
- b) During and/or after producing the three-dimen-

sional object, forming at least one cavity for receiving a reinforcement element in the three-dimensional object;

c) Insertion of a reinforcing element into the at least one cavity;

d) Casting of the reinforcing element inside the at least one cavity with a second curable binder composition which is chemically and/or physically different from the first curable binder composition.

[0021] Unless specified otherwise, in the present case, the general expression "curable binder composition" without further specification refers to both, the first and the second curable binder composition.

[0022] A "curable binder" denotes a material that can undergo a chemical reaction to harden into a solid. Typically curing of a curable binder is initiated by mixing with a hardening agent, by heating, by irradiation with electromagnetic waves and/or by exposure to humidity.

[0023] For example, the curable binder can be selected from reaction resins, mineral binders, mineral binder compositions or mixtures thereof.

[0024] Reaction resins are in particular liquid or liquefiable synthetic resins that harden into duroomers by polymerization and/or polyaddition. For example, unsaturated polyester resins, vinyl ester resins, acrylic resins, epoxy resins, polyurethane resins and/or silicone resins can be used.

[0025] A "curable mineral binder composition" is meant to be a material, which comprises a mineral binder and after addition of mixing water, can cure by a chemical reaction to form a solid.

[0026] The term "mineral binder" refers in particular to a binder which reacts in the presence of water in a hydration reaction to form solid hydrates or hydrate phases. This can be, for example, a hydraulic binder (e.g. cement or hydraulic lime), a latent hydraulic binder (e.g. slag), a pozzolanic binder (e.g. fly ash) or a non-hydraulic binder (e.g. gypsum or white lime).

[0027] A "mineral binder composition" is accordingly a composition containing at least one mineral binder. In particular, it contains the binder, aggregates and/or one or more additives. Aggregates may be, for example, gravel, sand (in natural and/or processed, e.g. crushed, form) and/or filler. The mineral binder composition is in particular a fluid mineral binder composition mixed with mixing water.

[0028] The expression "the curable binder composition in the setting state" in particular means that the curable binder composition is in a condition in which the setting of the binder in the curable binder composition has started but is not yet complete.

[0029] A mineral binder composition is in the setting state after mixing the mineral binder and optionally further components, such as e.g. aggregates, with the mixing water.

[0030] Especially, the first curable binder and/or the second curable binder are curable mineral binder compositions,

[0031] Especially, at least the first curable binder composition is a curable mineral binder compositions. In particular both, the first and the second curable binder compositions are curable mineral binder compositions.

[0032] However, in a special embodiment, the first curable binder composition is a curable mineral binder composition and the second curable binder is a reaction resin, in particular a epoxy resin and/or a polyurethane resin.

[0033] The mineral binder comprised in the curable mineral binder composition is preferably selected from the group consisting of cement, gypsum, burnt lime, slag, and fly ash, and mixtures thereof. The curable mineral binder composition preferably comprises at least one hydraulic binder, preferably a cementitious binder.

[0034] The hydraulic binder is preferably selected from the group consisting of Portland cement, calcium aluminate cement, calcium sulfoaluminate cement, and mixtures thereof.

[0035] The cement used may be any available cement type or a mixture of two or more cement types, examples being the cements classified under DIN EN 197-1: Portland cement (CEM I), Portland composite cement (CEM II), blast furnace slag cement (CEM III), pozzolanic cement (CEM IV), and composite cement (CEM V). Cements produced according to an alternative standard, such as the ASTM standard or the Indian standard, for example, are of course equally suitable. Particularly preferred is a cement according to DIN EN 197-1, a calcium sulfoaluminate cement, a calcium aluminat cement, or mixtures thereof, optionally in a mixture with calcium sulfate.

[0036] The most preferred is Portland cement or a cement including Portland cement according to DIN EN 197-1. Portland cement is particularly readily available and allows mortars to have good properties.

[0037] Also especially suitable are mixtures of Portland cement, calcium aluminate cement, and calcium sulfate, or mixtures of cement and calcium sulfoaluminate cement. Such binder mixtures allow short setting times and high early strengths.

[0038] The curable composition, in particular the curable mineral binder composition, preferably further comprises aggregates, especially mineral aggregates. Aggregates are chemically inert, solid, particulate materials and are available in various shapes, sizes and as different materials, varying from extremely fine particles of sand to large coarse stones. All aggregates typically employed for concrete and mortar are suitable in principle.

[0039] Examples of particularly suitable fillers are rock particle size fractions, gravel, sand, especially silica sand and limestone sand, comminuted stones, calcined pebbles or lightweight fillers such as expanded clay, expanded glass, foamed glass, pumice, perlite, and vermiculite. Other advantageous aggregates are calcium carbonate, aluminum oxide, amorphous silica (silica fume), or crys-

talline silica (quartz flour).

[0040] The particle size is guided by the application and is situated in the range from 1 μm to 32 mm or more. Preference is given to mixing different particle sizes in order to provide optimum establishment of the properties of the curable mineral binder composition. Aggregates composed of different materials can also be mixed. The particle size may be determined by means of sieve analysis.

[0041] Preferred aggregates are those having particle sizes of not more than 8 mm, more preferably not more than 5 mm, more preferably still not more than 3.5 mm, most preferably not more than 2.2 mm.

[0042] The curable binder composition, especially the curable mineral binder composition, preferably comprises aggregates of which at least 30 wt %, more preferably at least 40 wt %, most preferably at least 50 wt % are smaller than 2 mm, preferably smaller than 1 mm, more preferably smaller than 0.5 mm, based on a total amount of 100 wt % of all aggregates in the curable binder composition. Suitable aggregates of low particle size are, in particular, fine silica sands or calcium carbonate powders.

[0043] Curable binder compositions having such particle sizes are readily conveyable, can be mixed well in mixers, especially dynamic mixers.

[0044] There are specific applications in which aggregates having particle sizes of up to 32 mm may also be used, more preferably up to 20 mm, most preferably up to 16 mm.

[0045] Especially, the first and/or the second curable binder composition includes one or more additive(s).

[0046] As for example, the additive is a concrete admixture and/or a mortar admixture and/or a process chemical.

[0047] The additive may comprise a wetting agent, a die, a preservative, a plasticizer, a retarder, an accelerator, a polymer, a rheological assistant, a viscosity modifier, a pumping assistant, a shrinkage reducer, or a corrosion inhibitor, or combinations thereof.

[0048] A proportion of the additive in particular is from 0.001 - 15 wt.%, especially 0.01 - 10 wt.% with respect to the total weight of the curable binder composition.

[0049] Especially preferred, in the first curable binder composition, the additive is selected from accelerators and/or plasticizers.

[0050] An accelerator comprises for example at least one compound selected from the group consisting of amino alcohols, alkali metal and alkaline earth metal nitrates, alkali metal and alkaline earth metal nitrites, alkali metal and alkaline earth metal thiocyanates, alkali metal and alkaline earth metal halides, alkali metal and alkaline earth metal carbonates, glycerol, glycerol derivatives, glycols, glycol derivatives, aluminum salts, aluminum hydroxides, alkali metal and alkaline earth metal hydroxides, alkali metal and alkaline earth metal silicates, alkali metal and alkaline earth metal oxides, crystallization nuclei, and mixtures thereof.

[0051] An accelerator is preferably metered in an amount such that curable binder composition remains readily processable and/or shapeable for several seconds to several minutes. This allows the curable binder composition, especially the first curable mineral binder composition, for example to be used and optimized for additive manufacturing processes, e.g. 3D printing. Thereby, layers of the curable binder composition can be applied uniformly whereby said layers develop a good cohesion. Additionally, the surface of the shaped body produced can, if desired, be subsequently after treated for example.

[0052] Examples of suitable plasticizers include ligno-sulfonates, sulfonated naphthalene-formaldehyde condensates, sulfonated melamine-formaldehyde condensates, sulfonated vinylcopolymers, polyalkylene glycols having phosphonate groups, polyalkylene glycols having phosphate groups, polycarboxylates or polycarboxylate ethers, or mixtures of the stated plasticizers; polycarboxylate ethers are understood to comprise comb polymers having anionic groups on the polymer backbone and having polyalkylene oxide side chains, the anionic groups being selected in particular from carboxylate groups, sulfonate groups, phosphonate groups, or phosphate groups.

[0053] In particular, in the second curable binder composition, the additive is selected from plasticizers and/or shrinkage reducers.

[0054] A shrinkage reducer can e.g. be selected from polyoxyalkylenes, alkylamines, and/or oxyalkylamines.

[0055] In particular, the first and/or the second curable binder composition is produced in the setting state by mixing of the components of the curable binder composition in a mixing unit. Most preferably, the first curable binder composition is continuously produced in the setting state, especially during the application of the curable binder composition in step a) and/or the second curable mineral binder composition is produced in the setting state during step d).

[0056] In particular, the first and/or the second curable binder composition is introduced into a mixing unit, especially a dynamic mixing device, of the additive manufacturing device in dry form and/or in the form of a dry mortar or dry concrete composition. Thereby, a hardener or water preferably is added into the mixing unit separately from the curable mineral binder composition to produce the curable binder composition in the setting state in the mixing device.

[0057] Further preferred, if used, the at least one additive is added to the mixing device separately from the curable binder composition(s) too. However, it might be added together with the water and/or other components.

[0058] Separately introducing water and/or the additive into the mixing device allows for controlling the flow, setting and/or hardening properties of the curable binder composition precisely during step a) and/or step d).

[0059] In another preferred embodiment, the first and/or the second curable binder composition is intro-

duced into the mixing unit in wet form and/or in the form of a mortar or concrete composition premixed with water and optionally at least one further additive as described above, e.g. a plasticizer.

[0060] Especially, the first and/or the second curable binder composition comprises a mineral binder and aggregates, especially sand. Thereby, preferably, a weight ratio of the aggregates to the mineral binder is from 5:1 - 1:2, especially 4:1 - 1.2:1.

[0061] Highly preferred, water in the first and/or the second curable binder composition, especially curable mineral binder composition, is used with a proportion of 25 - 70 wt.%, especially 30 - 50 wt.%, in particular 35 - 45 wt.%, with respect to the total weight of the binder, especially mineral binder, in the binder composition.

[0062] The forming of the at least one cavity for receiving a reinforcement element in the three-dimensional object in step b) can take place during and/or after step a) or the production of the three-dimensional object, respectively.

[0063] In a highly preferred embodiment, the at least one cavity is at least partly, especially completely, formed during step a) by appropriate shaping of the three-dimensional object. Thereby, steps a) and b) at least partly take place simultaneously.

[0064] In this case, preferably, the at least one cavity is defined in a structural data model of the three-dimensional object used to produce the three-dimensional object with the additive manufacturing device. The structural data model may be stored in a memory module of a control unit of the additive manufacturing device

[0065] Forming the at least one cavity at least partly during step a) allows for reducing the effort required to subsequently forming the cavity in the already produced three-dimensional object and the dimension, position and/or volume of the cavity can be optimized in view of the reinforcement required.

[0066] However, it is also possible to form the at least one cavity at least partly, especially completely, by removing material from the produced three-dimensional object after step a). Thereby, at least partly, step b) takes place after step a). Removing material can e.g. be effected by drilling, milling and/or blasting.

[0067] Such an implementation allows for example for deciding about the position of the reinforcement after the three-dimensional object has been produced. This approach is somehow more flexible since the dimension of the at least one cavity can be adapted to the reinforcement element without need for providing another data model of the three-dimensional object to be produced.

[0068] Especially, the two approaches for forming the cavities can be combined. For example, a first section of the at least one cavity, e.g. an inner part of the at least one cavity, can be formed during step a) while a second section, e.g. an outer part of the at least one cavity, is formed after step a) by removing material from the produced three-dimensional object. In this case, the effort for removing the material can be reduced while the at

least one cavity can still be adapted to the reinforcement element to a certain extent.

[0069] As mentioned above, the first and the second curable binder composition in a preferred embodiment both are curable mineral binder compositions.

[0070] Thereby, especially preferred, the second curable mineral binder composition comprises the same type of mineral binder and the same type of aggregates as the first curable mineral binder composition, whereby preferably the weight proportions of the mineral binders and the aggregates are identical in the two curable mineral binder compositions.

[0071] In particular, in terms of the solid components, the second curable mineral binder composition is identical with the first curable mineral binder composition.

[0072] Thereby, the curable mineral binder composition can for example be produced from one and the same dry mortar or concrete composition. This makes the overall process more efficient and the chemical and/or physical difference between the two curable mineral binder compositions can e.g. be produced by different proportions of water, different additives and/or different proportion of an additive.

[0073] Thus, in particular, the second curable mineral binder composition differs from the first mineral binder composition, especially exclusively, in the proportion of water, the nature of an additive and/or a proportion of an additive.

[0074] Especially, a proportion of water to the mineral binder is lower in the first curable mineral binder composition when compared with the second curable mineral binder composition. This allows for producing a second curable mineral binder composition that is more fluid than the first one.

[0075] In particular, the second curable binder composition, especially a curable mineral binder composition, has a lower viscosity than the first binder composition, especially a curable mineral binder composition.

[0076] Curable binder compositions with good flowability and/or low viscosity are highly suitable for casting the reinforcing element inside the at least one cavity. However, for producing the three-dimensional object by additive manufacturing in step a), a curable binder composition with higher viscosity and/or lower flowability is better suitable.

[0077] Especially preferred, the second curable binder composition is a self-levelling composition. Self-levelling compositions are very fluid binder compositions than can be placed and tightened under the alone effect of gravity, especially without calling for any vibrations.

[0078] In particular, the self-levelling composition has a consistency class of at least S4, especially S5, and/or it has a slump of 160 - 210 mm, especially ≥ 220 mm, according to EN 206-1:2013 + A1 2016.

[0079] A consistency class of the first binder composition preferably is S1, S2 or S3 and/or it has a slump of at most 150 mm, according to EN 206-1:2013 + A1 2016.

[0080] Especially, the reinforcement element is a rod

or a ribbon.

[0081] In particular, the reinforcement element is made from metal, plastics, fiber composite materials, glass fiber reinforced plastics, carbon fiber reinforced plastics. Plastics can e.g. be selected from epoxy resins, epoxy vinyl ester resin, polyamide, polyvinyl alcohol and/or poly(ethylene-vinyl acetate).

[0082] In particular the reinforcement element is made from metal, especially steel. In particular, the reinforcement element is a steel rod.

[0083] However, in another embodiment, the reinforcement element is made from synthetic material, especially a composite material comprising load-bearing fibres kept together by an organic synthetic material. Thereby, preferably, the load-bearing fibres are fully impregnated and embedded within the organic synthetic material.

[0084] The load-bearing fibres may comprise carbon fibers, basalt fibers, glass fibers and/or synthetic fibers, whereby the synthetic fibers are selected from aramid fibers, polyhydroquinone-diimidazopyridine fibers and/or poly(p-phenylene-2,6-benzobisoxazol) fibers. Especially, the load-bearing fibres consist of carbon fibers.

[0085] The organic synthetic material may be a thermoset and/or a thermoplastic, especially selected from epoxy resins, epoxy vinyl ester resin, polyamide, polyvinyl alcohol and/or poly(ethylene-vinyl acetate).

[0086] With respect to the total weight of a composite material, the composite material may comprise 40 - 99 wt.%, especially 50 - 95 wt.%, of load-bearing fibers and 1 - 60 wt.% especially 5 - 50 wt.%, of the organic synthetic material.

[0087] Especially, in step c) at least one reinforcing element, in particular exactly one reinforcing element, is inserted into the at least one cavity.

[0088] In case of more than one cavity, at least one, especially exactly one, reinforcing element preferably is inserted in each cavity.

[0089] Insertion of a reinforcing element into the at least one cavity in particular takes place after steps a) and/or b).

[0090] Especially, a shape of the hollow space of the at least one cavity is cylindrical, prismatic and/or cuboid. For example, the shape is circular cylindrical, triangular prismatic and/or rectangular cuboid. However, more complex shapes can be realized as well, especially if several reinforcing elements cross each other in the three-dimensional object.

[0091] The at least one cavity preferably has a length of at least 50%, especially at least 75%, in particular 80 - 100%, of the length the three-dimensional object in a direction of the longitudinal axis of the at least one cavity. Especially, the longitudinal axis of the at least one cavity runs along the length, the width or the height of the three-dimensional object.

[0092] Especially, the reinforcement element introduced in the at least one cavity has a length of at least 50%, especially at least 75%, in particular 80 - 120%, of

the length of the at least one cavity and/or of a length of the three-dimensional object in a direction of the longitudinal axis of the at least one cavity.

[0093] Thus, in this case, the reinforcing element extends over a significant length, width and/or height of the three-dimensional object resulting in an effective reinforcement of the three-dimensional object.

[0094] In a special embodiment, the reinforcement element introduced into the at least one cavity has a length more than 100%, especially at least 105%, in particular at least 110%, of the length of the at least one cavity and/or of a length of the three-dimensional object in a direction of the longitudinal axis of the at least one cavity. Such a configuration is for example advantageous if the three-dimensional object needs to be prestressed as described in the following.

[0095] Further preferred, after step c) and/or after step d), the three-dimensional object is prestressed along the direction of the reinforcing element. This can be used to further increase the load capacity of the three-dimensional object.

[0096] Especially, the three-dimensional object is prestressed such that the three-dimensional object bends in a direction against an intended load direction of the three-dimensional object. Thereby, in particular, the reinforcing element runs in an essentially horizontal direction and/or the reinforcing element, with respect to a vertical direction of the three-dimensional object, is arranged in a lower half, especially in a lower quarter, of the three-dimensional object.

[0097] In particular, prestressing is realized by compressing the three-dimensional object and keeping it in the compressed position with the help of the reinforcing element. In this case, for example, the reinforcement element introduced in the at least one cavity has a length more than 100% of the length of the at least one cavity and/or of a length of the three-dimensional object in a direction of the longitudinal axis of the at least one cavity.

[0098] The free ends of the reinforcing element then can be used to attach at each free end a stop element. Especially, the stop element is larger in size than a cross section perpendicular to the longitudinal axis of the at least one cavity. In this case, the stop element cannot enter the cavity. The stop element can e.g. be a nut, a splint, a clamp and/or a thickened section of the free end.

[0099] Preferably one of the stop elements is movable in a direction along the longitudinal axis of the reinforcing element. Especially, the stop element is a nut received on thread on at least one the free ends.

[0100] The term "additive manufacturing method" or "additive manufacturing" refers to methods in which a three-dimensional object is produced by selective three-dimensional deposition, application and/or solidification of material. In this process, the deposition, application and/or solidification of the material takes place in particular based on a data model of the object to be produced, and in particular in layers or sheets. In the additive manufacturing method, each object is typically produced from

one or a plurality of layers. Accordingly, an additive manufacturing device is a device capable of performing such methods.

[0101] Especially, in step a) the three-dimensional object is applied with the additive manufacturing device in at least one layer, especially in a plurality of layers. Thereby, preferably, the application is effected by means of a print head that is moveable in at least one, especially in three, spatial direction(s).

[0102] The additive manufacturing device used in the present invention in particular performs a generative free space additive manufacturing process. This means that the three-dimensional object is formed layer by layer, namely by applying the first curable mineral binder composition only at those points where the three-dimensional object is to be formed. In the case of overhangs and/or cavities, a support structure can optionally be provided. In contrast, in powder bedding or liquid processes, for example, the entire space is typically filled and the material is then selectively solidified at the desired locations.

[0103] Free-space processes have proved to be particularly advantageous in connection with the production of reinforced three-dimensional objects from curable mineral binder compositions.

[0104] The three-dimensional object produced in step a) can have almost any desired shape and can, for example, be a finished part for a structure, e.g. for a building, a masonry structure and/or a bridge.

[0105] In particular, the additive manufacturing device comprises:

- a mixing unit, especially a dynamic mixing device, for producing the first curable binder and/or the second curable binder composition in the setting state;
- a printing head movable in at least one spatial direction, especially with a movement device, for applying the first curable binder composition and/or the second curable binder composition in the setting state.

[0106] The mixing unit for producing the first curable binder and/or the second curable binder composition in the setting state can be included in the printing head and/or it can be located at a position spaced apart from the printing head.

[0107] In the first case, the components of the curable binder composition can be conveyed separately via supply lines to the mixing unit. In the latter case, the additive manufacturing device additionally comprises a supply line for conveying the curable binder composition in the setting state from the mixing unit to the printing head.

[0108] Optionally the additive manufacturing device furthermore comprises at least one additive supply device whereby the additive supply device preferably is arranged at the printing head and/or in a supply line upstream the printing head, which additive supply device is configured to add an additive to the curable binder composition in the setting state. This allows for specifi-

cally adjusting the properties of the curable binder composition in the setting state by adding the additive before the binder composition is applied with the printing head.

[0109] Especially preferred, in step a) the first curable binder composition produced in the mixing unit is applied with the printing head, especially in a layer-by-layer application, to produce the three-dimensional object in step a).

[0110] For applying the first curable binder composition in the setting state, the printing head is in particular controlled on the basis of a structural data model of the three-dimensional object. The structural data model may be stored in a memory module of a control unit of the additive manufacturing device.

[0111] Preferably, both curable binder compositions are produced in the same mixing unit of the additive manufacturing device. Thereby, preferably, the first curable binder composition is produced with a first additive and the second binder composition is produced with a second additive, whereby the first and the second additive are chemically different.

[0112] This turned out to be highly effective without need for additional equipment.

[0113] In particular, the additive manufacturing device comprises two separate inlets for introducing the two different additives separately into the mixing unit and/or a switchable valve, which allows for introducing either the first or the second additive.

[0114] Especially, the first additive comprises an accelerator and/or a plasticizer; and/or the second additive comprises a plasticizer and/or a shrinkage reducer.

[0115] Especially, the mixing device of the additive manufacturing device is a dynamic mixing device. This is meant to be a mixing device whereby the mixing is effected by at least one moving mixing element. In contrast, a static mixer is a mixing device without any moving mixing elements.

[0116] Especially, the dynamic mixing device comprises at least one dynamic mixing element, especially a rotatable mixing element, for mixing the components, which is operated at a speed of 500 - 2'000, especially 600 - 1'700, most preferably of 1'000 to 1'500, revolutions per minute.

[0117] The mean residence time of the components in the dynamic mixing device in step b) in particular is from 1 - 30 s, especially 5 - 20 s, in particular 10 - 15 s. The mean residence time of the curable binder composition in the dynamic mixing device is the average period of time for which a particle resides in the dynamic mixing device, from introduction to the removal. The mean residence time can for example be controlled by the conveying speed of the components introduced into and/or removed from the dynamic mixing device.

[0118] The dynamic mixing device preferably comprises a drum having at least one inlet and one outlet, a drive, a stirring shaft for mixing the components, said stirring shaft being arranged in the drum and being coupled to the drive. In this embodiment, the stirring shaft is a special

kind of a stirring element.

[0119] In one advantageous exemplary embodiment, the stirring shaft is equipped with pegs such that, while the stirring shaft rotates, a mix in the drum is moved by the pegs. This has the advantage that, as a result, efficient and homogeneous mixing of the different components can be achieved. Furthermore, a specific arrangement and configuration of the pegs can influence both mixing and conveying of the mix in the drum.

[0120] Such stirring shafts having pegs are suitable in particular for mixing components with large grain sizes, for example grain sizes of 2 to 10 mm. These can be for example aggregates such as stones, gravel or sand. In addition, such a mixer is also suitable for mixing asymmetrical substances, for example mixes having fiber admixtures (for example carbon fibers, metal fibers or synthetic fibers).

[0121] In an alternative exemplary embodiment, the stirring shaft is not equipped with pegs but is configured for example as a helical stirrer, disk stirrer or inclined-blade stirrer.

[0122] More preferably, the dynamic mixing device is connected with a conveying device and/or it comprises a conveying device. Especially preferred, the conveying device is arranged in the drum.

[0123] In one advantageous embodiment, the conveying device is arranged in a manner directly adjoining the stirring shaft such that the mix mixed by the stirring shaft is able to be collected directly by the conveying device and is able to be conveyed out of the drum through the outlet.

[0124] In one advantageous exemplary embodiment, the conveying device and the stirring shaft are arranged on one and the same driveshaft, wherein said driveshaft is drivable by the drive. This has the advantage of resulting in a cost-effective and robust device.

[0125] In an alternative exemplary embodiment, the conveying device and the stirring shaft are arranged on two separate driveshafts, wherein the conveying device is arranged on a first driveshaft and the stirring shaft is arranged on a second driveshaft, with the result that the conveying device and stirring shaft are drivable at different speeds. Such an arrangement has the advantage that, as a result, the mixing and conveying of the mix can be set separately from one another. In this way, for each particular purpose, optimum mixing and conveying can be achieved through a specifically adaptable mixing rate and conveying rate. For example, for a first application, slight mixing with a simultaneously high conveying rate and/or conveying at high pressure may be advantageous, and for a second application, intensive mixing with a simultaneously low conveying rate and/or conveying at low pressure may be advantageous.

[0126] In one advantageous exemplary embodiment, the stirring shaft and the conveying device are arranged next to one another in the drum, wherein the stirring shaft is arranged in a first drum section and the conveying device is arranged in a second drum section, and wherein

the inlet is arranged in the first drum section and the outlet is arranged in the second drum section.

[0127] In one advantageous development, the first drum section with the stirring shaft arranged therein forms between 50% and 90%, preferably between 60% and 85%, particularly preferably between 70% and 80%, of a volume of the drum. It has been found that, as a result of such a division of the drum, an optimum mixing rate with a desired conveying rate of the mixer can be achieved.

[0128] In one advantageous exemplary embodiment, the conveying element is configured as a screw conveyor. In one advantageous development, the screw conveyor has at least one, preferably at least two turns. Such a screw conveyor has the advantage that, as a result, even highly viscous mixes can be conveyed in the drum and, in addition, can be conveyed out of the drum through the outlet at a desired pressure.

[0129] In a further advantageous development, a cross section of a shaft of the conveying device can be configured in a variable manner in the direction of the driveshaft. In this case, a volume for the mix becomes smaller toward one end of the conveying device. As a result, a conveying pressure of the conveying device can be changed depending on the orientation of the reduction in size of the volume for the mix.

[0130] In one advantageous development, more than two turns can be formed. In addition, the turns can have different extents in the direction of the driveshaft, wherein the turns become tighter toward one end of the conveying device. As a result, a conveying pressure of the conveying device can be changed depending on the orientation of the tightening of the turns.

[0131] Especially, the dynamic mixing device is connected with a feed device with which the binder, aggregates, water and/or at least one additive can be added to the mixing device, preferably independently of each other. For this, the feed device preferably has at least two, especially at least three, separate inlets configured for discharging the components individually into the dynamic mixing device. With that, the composition of the curable binder composition(s) can be adapted at any time and in a flexible manner.

[0132] In order to mix components together and to convey them, it is possible for only one inlet or two or more inlets to be arranged on the drum. In this case, the components can for example be combined before they are passed into the drum, or the components can be passed into the drum via separate inlets and only be mixed together once they are in the drum.

[0133] Depending on the number and arrangement of the inlets, the stirring shaft and the stirring elements arranged thereon, such as pegs, for example, can be configured differently.

[0134] Especially, the second curable binder is produced in the mixing unit of the additive manufacturing device and filled in the at least one cavity with the printing head for casting of the reinforcing element inside the at

least one cavity in step d).

[0135] This further reduces the equipment required. However, it is possible as well to fill the second curable binder into the at least one cavity with a separate device and/or manually.

[0136] A further aspect of the present invention is directed to a reinforced three-dimensional object produced by an additive manufacturing process, especially obtainable by a method as described above, whereby the reinforced three-dimensional object is made from a first curable binder composition, especially a curable mineral binder composition, whereby at least one reinforcement element is casted in at least one cavity of the three-dimensional object with a second curable binder composition, especially a curable mineral binder composition, which is chemically and/or physically different from the first curable mineral binder composition.

[0137] Further advantageous implementations of the invention are evident from the exemplary embodiments.

Brief description of the drawings

[0138] The drawings used to explain the embodiments show:

Fig. 1 a schematic illustration of an exemplary dynamic mixing device with integrated conveying device suitable for producing curable mineral binder compositions;

Fig. 2 a schematic illustration of a mixing device for mixing a pulverulent components and liquid components;

Fig. 3 a schematic illustration of an exemplary additive manufacturing device with the mixing device of Fig. 1 arranged on the printing head suitable for applying curable mineral binder compositions;

Fig. 4 a cuboid element reinforced with a steel bar in a central cavity produced according to the inventive method;

Fig. 5 a table reinforced with four steel bars produced according to the inventive method;

Fig. 6 a cross section through a further three-dimensional object that was produced with the inventive method and prestressed with the reinforcing element and additional stop elements;

Fig. 7 a cross section through a still further three-dimensional object that was produced with the inventive method and prestressed such that the three-dimensional object bends in a direction against an intended load.

Exemplary embodiments

Method and device for additive manufacturing

[0139] Fig. 1 illustrates an exemplary mixer 1. The mixer 1 has a drive 3, a drum 2, a stirring shaft 4, and a conveying device 5. The drum 2 in this case has two inlets 6 and one outlet 7. The inlets 6 are in this case located in a first drum section 10, in which the stirring shaft is arranged, and the outlet 7 is located in a second drum section 11, in which the conveying device 5 is also arranged.

[0140] In this exemplary embodiment, two inlets 6 are arranged on the drum 2. In an alternative exemplary embodiment, which is not illustrated, the drum 2 can for example have only one inlet, however. In this case, the components to be mixed can already be combined before they are conveyed into the drum 2 via the inlet. In other alternative embodiments, the drum can have three or more inlets for introducing three or more components to be mixed separately.

[0141] In this case, the conveying device 5 is arranged in a manner directly adjoining the stirring shaft 4 such that the mix mixed by the stirring shaft 4 is able to be collected directly by the conveying device 5 and is able to be conveyed out of the drum 2 through the outlet 7.

[0142] In this exemplary embodiment, the conveying device 5 is configured as a screw conveyor. The screw conveyor in this exemplary embodiment has two complete turns 9. Depending on the desired conveying rate, the screw conveyor can be dimensioned or configured in some other way. The conveying device 5 and the stirring shaft 4 are arranged on one and the same axis in the drum 2. In this exemplary embodiment, the stirring shaft 4 is equipped with pegs 8 such that, while the stirring shaft rotates, a mix in the drum is moved by the pegs 8.

[0143] Fig. 2 again illustrates an exemplary mixer 1 having a feeding device 12 at one of the inlets. A first component 20, and a second component 22 are continuously fed to the mixer 1 via a first feed line 21 and via a second feed line 23, respectively.

[0144] For example, in this case, the first component 20 can be a pulverulent component, e.g. a curable mineral binder composition in the form of a dry mortar composition, which is fed into the hopper of the feeding device 12 via the first feed line 21, and the second component 22 can be for example a liquid or pumpable substance, e.g. water and optionally an additive, e.g. plasticizer, which is passed directly into the drum of the mixer 1 via the second feed line 23.

[0145] During the mixing operation, the dry mortar composition is mixed with water and the optional additive, whereby a curable mineral binder in the setting state is produced which is conveyed through the outlet 25 of the mixer by the conveying device 5.

[0146] Fig. 3 illustrates an additive manufacturing device 100 for applying a curable mineral binder composition for producing a three-dimensional object.

[0147] The system 100 comprises a movement device 102 with a movable arm 102.1. A print head 103 is attached to the free end of the arm 102.1, which can be moved by the arm 102.1 in all three spatial dimensions. Thus, the print head 103 can be moved to any position in the working area of the motion device 102.

[0148] Inside, the print head 103 has a tubular passage 103.1 passing through from the end face facing the arm 102.1 (at the top in Fig. 3) to the opposite and free end face. The tubular passage is configured for conveying a curable binder composition. At the free end, the passage 103.1 opens into an outlet nozzle 104.

[0149] The print head 103 comprises a first inlet device 105 consisting of a supply device, e.g. a pump, and an inlet nozzle, which opens into passage 103.1. Through the inlet nozzle of the inlet device 105, an additive, for example a rheological aid, can be added to the curable binder composition flowing through the passage 103.1 as required.

[0150] Furthermore, inside the print head 103, downstream with respect to the inlet devices, a dynamic mixer 106 is arranged in the passage 103.1, which additionally mixes the curable binder composition and the additive. However, the dynamic mixer 106 is optional and can for example be replaced by a static mixer or omitted.

[0151] The system 100 for applying a curable building material also has a feed device 109 which corresponds on the input side to three containers 111.1, 111.2, 111.3 and an additive reservoir 111.4. Each of the three containers 111.1, 111.2, 111.3 contains one component of the curable building material. The first component, which is present in the first container 111.1, is a dry mineral binder composition, e.g. cement or dry mortar. The second component, which is present in the second container 111.2, consists of water, for example. The third component present in the third reservoir 111.3 is, for example, a superplasticizer in the form of a polycarboxylate ether. In the additive reservoir 111.4 there is present, for example, a rheological aid in the form of modified cellulose and/or a microbial polysaccharide.

[0152] On the output side, the feed device 109 has three separate outlets, each of which is connected to one of three inlets 6a, 6b, 6c of a mixing device 1'. The feed device 109 also has individually controllable metering devices (not shown in Fig. 3), so that the individual components in the individual containers 111.1, 111.2, 111.3 can be metered individually into the mixing device 1'.

[0153] A further outlet of the feed device is connected to the inlet nozzle 105 (not shown in Fig. 3), so that additive can be fed from the additive reservoir 111.4 into the inlet nozzle 105 via a further metering device of the feed device 109.

[0154] The mixing device 1' is similar in design to the mixing device shown in Fig. 1 but has three inlets 6a, 6b, 6c. In the mixing device 1', the individually metered components are mixed together and conveyed into the flexible line 112 attached to the outlet side of the mixing device 1'. In operation, the mixing and conveying of the

curable binder composition can take place continuously.

[0155] The curable binder composition can be conveyed into the print head 103 via the flexible line 112, which opens into the tubular passage 103.1, and continuously applied through the outlet nozzle 104.

[0156] Also, part of the system 100 is a measuring unit 113, which is integrated into the delivery line 112 in the area between the mixing device 100 and the print head 103. The measuring unit includes, for example, an ultrasonic transducer which is designed to determine the flow properties of the curable material.

[0157] A central control unit 114 of the system 100 includes a processor, a memory unit, and a plurality of interfaces for receiving data and a plurality of interfaces for controlling individual components of the system 100.

[0158] In this regard, the mixing device 1' is connected to the control unit 114 via a first control line 115a, while the feeding device 109 is connected to the control unit 114 via a second control line 115b. As a result, the individual components in the containers 111.1, 111.2, 111.3 can be metered into the mixing device 1' via the central control unit in accordance with predetermined recipes stored in the control unit and conveyed into the flexible line 112 at adjustable conveying rates.

[0159] The inlet device 105 is connected to the control unit 114 via a separate control line 115c and can be controlled or monitored by the control unit 114 too.

[0160] The movement device 102 is also connected to the control unit 114 via a further control line 115d. This means that the movement of the print head 103 can be controlled via the control unit 114.

[0161] Similarly, the measuring unit 113 is connected to the control unit 114 by a control line 115e, so that data recorded in the measuring unit characterizing the flow properties can be transmitted to the control unit 114.

[0162] A structural data model of the three-dimensional object to be produced may be stored in a memory module of a control unit 114 of the additive manufacturing device 100.

[0163] In this configuration, the additive manufacturing device 100 can be operated as a "two-component system" in which an additive is added separately as a second component to the other constituents of the curable binder composition representing a first component.

[0164] However, in another embodiment, all of the constituents the curable binder composition, including an optional additive, can be premixed in the mixing device 1'. Thereby, the manufacturing device 100 is operated as a "one-component system" without addition of an additive through inlet device 105. In this case, manufacturing device 100 the inlet device 105 and related elements can even be omitted to simplify the setup.

Production of reinforced three-dimensional objects

[0165] For producing reinforced three-dimensional objects, SikaCrete®-7100 3D (available from Sika USA) was used as the first curable mineral binder composition.

This is a multi-component fiber-containing micro-concrete ink system developed for 3D printing comprising (i) a dry mortar composition with Portland cement and sand, (ii) an accelerating additive and plasticizing polymer admixture.

[0166] The components were continuously introduced at a constant rate into the mixing device shown in Fig. 2 and continuously mixed at a speed of for example 800 rpm.

[0167] The so produced first mineral curable mineral binder composition was applied with the printing head 103 of the additive manufacturing device 100 to produce the unreinforced parts UP of two three-dimensional objects in the form of (i) a cuboid object (Fig. 4) and (ii) a table-like object (Fig. 5).

[0168] The cuboid object of Fig. 4 was produced as follows: After having produced the unreinforced part UP of the cuboid with a central cylindrical cavity, a steel bar RB was introduced as reinforcing element in the cavity. The steel bar RB extends along the whole width of the cuboid element.

[0169] Finally, the steel bar RB was casted inside the cavity with a second curable mineral binder composition in the form of a self-leveling mortar SL. The self-leveling mortar SL consisted of the same pulverulent component as the first curable mineral binder composition, but was mixed with a different plasticizing additive and an anti-shrinkage agent in order to obtain the self-levelling properties.

[0170] The table-like object of Fig. 5 was produced as follows: After having produced the unreinforced part UP of the table, two cavities in the form of round holes running in parallel along the longitudinal axis of the table were drilled through the solid material of the table-like object. Additionally, the table-like object comprises two additional cavities at the bottom side running perpendicular to the longitudinal axis of the table-like object. The additional cavities have been formed during the production of the unreinforced part UP of the table.

[0171] Subsequently, in each of the cavities a steel bar RB was introduced as reinforcing element. The steel bars RB extend along the whole length or width, respectively, of the table.

[0172] Finally, similar to the cuboid element of Fig. 4, the steel bars RB were casted inside the cavities with a second curable mineral binder composition in the form of the self-leveling mortar SL as described above.

[0173] After 7 days of curing, the table of Fig. 5 was tested in terms of mechanical stability. It turned out that a flexural strength of > 20 MPa could be achieved. For reasons of comparison, the flexural strength of the unreinforced table was measured. Thereby a much lower flexural strength of about only 8 - 9 MPa was observed. This proves that the inventive method allows for effectively reinforcing 3D printed objects made of mineral binder compositions.

[0174] Fig. 6 shows a cross-section through a further reinforced three-dimensional object that was produced

according to the inventive method. Thereby the unreinforced parts UP of the three-dimensional object was produced with a cavity C running in horizontal direction. Afterwards, a steel bar RB was introduced as reinforcing element in the cavity C whereby a length of the steel bar RB is about 110% of the length of the cavity C. The free ends of the steel bar RB protruding out of the cavity C are equipped with a thread.

[0175] Subsequently, after filling the cavity C with a self-leveling mortar SL, on each free end of the steel bar RB, a stop element in the form of a nut SE.1, SE.2 was screwed onto the threads. Perpendicular to the longitudinal axis of the cavity C, the nuts are SE.1, SE.2 larger in size than the cross section of the cavity C so that they cannot enter the cavity C.

[0176] By tightening the nuts SE.1, SE.2, the three-dimensional object was compressed and prestressed with the help of the steel bar RB in the lower section.

[0177] Fig. 7 shows another cross-section through a still further reinforced three-dimensional object that was produced according to the inventive method. The object of Fig. 7 is essentially identical in design with the object shown in Fig. 6. However, a higher compressive force or prestress, respectively, was applied, such that the three-dimensional object bends in a direction upwards as indicated by the arrows pointing upwards in Fig. 7.

[0178] The prestressing shown in Fig. 6 and 7 can be used to further increase the load capacity of the three-dimensional objects.

[0179] It will be appreciated by those skilled in the art that the present invention can be implemented in other specific forms without departing from the spirit or essential characteristics thereof. The presently disclosed embodiments and embodiments are therefore considered in all respects to be illustrative and not restricted.

Claims

1. A method for producing a reinforced three-dimensional object from a binder composition with an additive manufacturing process, the method comprising the steps of:

- a) Applying a first curable binder composition, especially a first curable mineral binder composition, in the setting state with an additive manufacturing device, especially having a movable printing head, to produce the three-dimensional object;
- b) During and/or after producing the three-dimensional object, forming at least one cavity for receiving a reinforcement element in the three-dimensional object;
- c) Insertion of a reinforcing element into the at least one cavity;
- d) Casting of the reinforcing element inside the at least one cavity with a second curable binder

composition, especially a second curable mineral binder composition, in the setting state which is chemically and/or physically different from the first curable binder composition.

2. The method according to claim 1, whereby the at least one cavity is at least partly, especially completely, formed during step a).
3. The method according to any of previous claims, whereby the at least one cavity is at least partly, especially completely, formed by removing material from the produced three-dimensional object after step a).
4. The method according to any of previous claims, whereby both curable binder compositions are curable mineral binder compositions and the second curable binder composition comprises the same type of mineral binder and the same type of aggregates as the first curable binder composition, whereby preferably the weight proportions of the mineral binders and the aggregates are identical in the two curable binder compositions.
5. The method according to any to any one of previous claims, whereby in terms of the solid components, the second curable binder composition is identical with the first curable binder composition.
6. The method according to any to any one of previous claims, whereby the second curable binder composition differs from the first binder composition, especially exclusively, in the proportion of water, the nature of an additive and/or a proportion of an additive.
7. The method according to any to any one of previous claims, whereby the second curable binder composition has a lower viscosity than the first binder composition
8. The method according to any to any one of previous claims, whereby the second curable binder composition is a self-levelling composition, in particular, the self-levelling composition has a consistency class of at least S4, especially S5, and/or it has as slump of 160 - 210 mm, especially ≥ 220 mm, according to EN 206-1:2013 + A1 2016.
9. The method according to any to any one of previous claims whereby the reinforcement element is a rod, especially a metallic rod, in particular a steel rod.
10. The method according to any to any one of previous claims whereby the reinforcement element introduced in the at least one cavity has a length of at least 50%, especially at least 75%, in particular 80 - 120%, of the length of the at least one cavity and/or

of a length of the three-dimensional object in a direction of the longitudinal axis of the at least one cavity.

11. The method according to any to any one of previous claims whereby the additive manufacturing device comprises: 5
- a mixing unit, especially a dynamic mixing device, for producing the first curable binder and/or the second curable binder composition, in the setting state; 10
 - a printing head movable in at least one spatial direction, especially with a movement device, for applying the first curable binder and/or the second curable binder composition in the setting state. 15
12. The method according to any to claim 11, whereby in step a) the first curable binder composition produced in the mixing unit is applied with the printing head in a layer-by-layer application to produce the three-dimensional object. 20
13. The method according to any to any of claims 11 - 12, whereby both curable binder compositions are produced in the same mixing unit of the additive manufacturing device. 25
14. The method according to any to any of claims 11 - 13 whereby the second curable binder is produced in the mixing unit of the additive manufacturing device and filled in the at least one cavity with the printing head for casting of the reinforcing element inside the at least one cavity in step d). 30 35
15. A reinforced three-dimensional object obtainable by a method according to any of previous claims. 40

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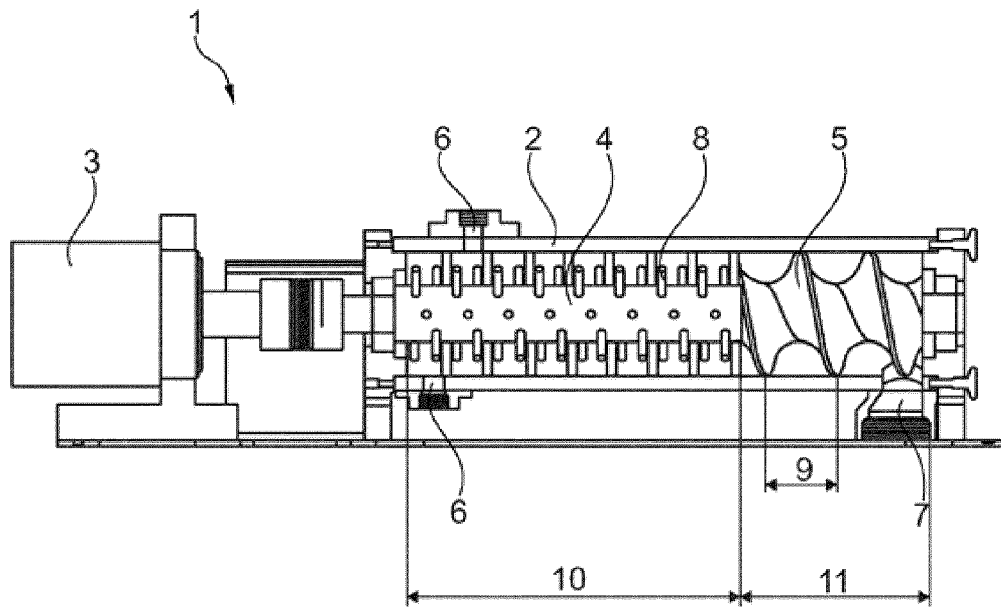


Fig. 1

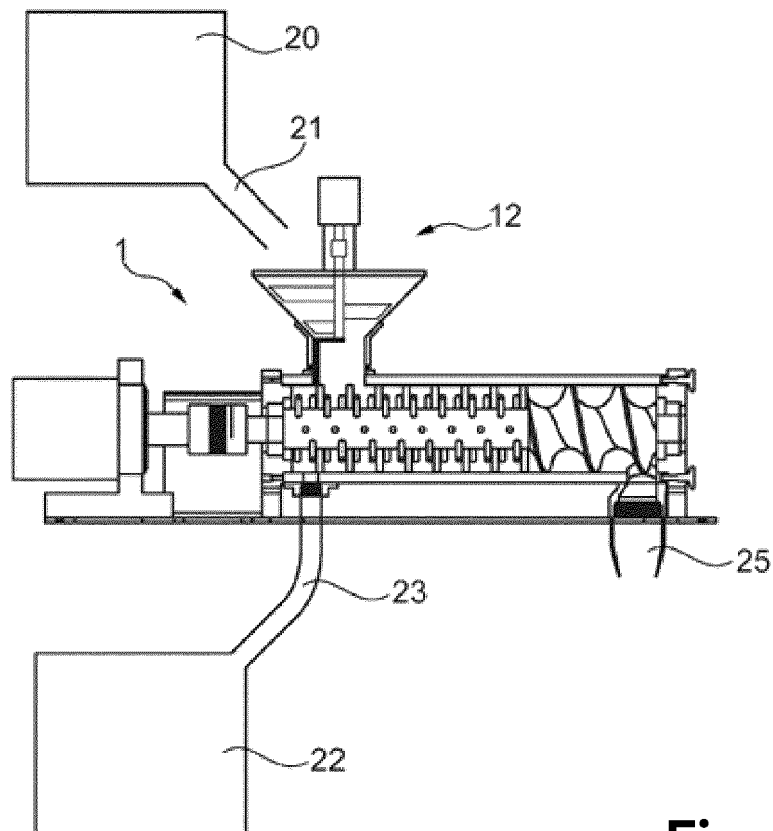


Fig. 2

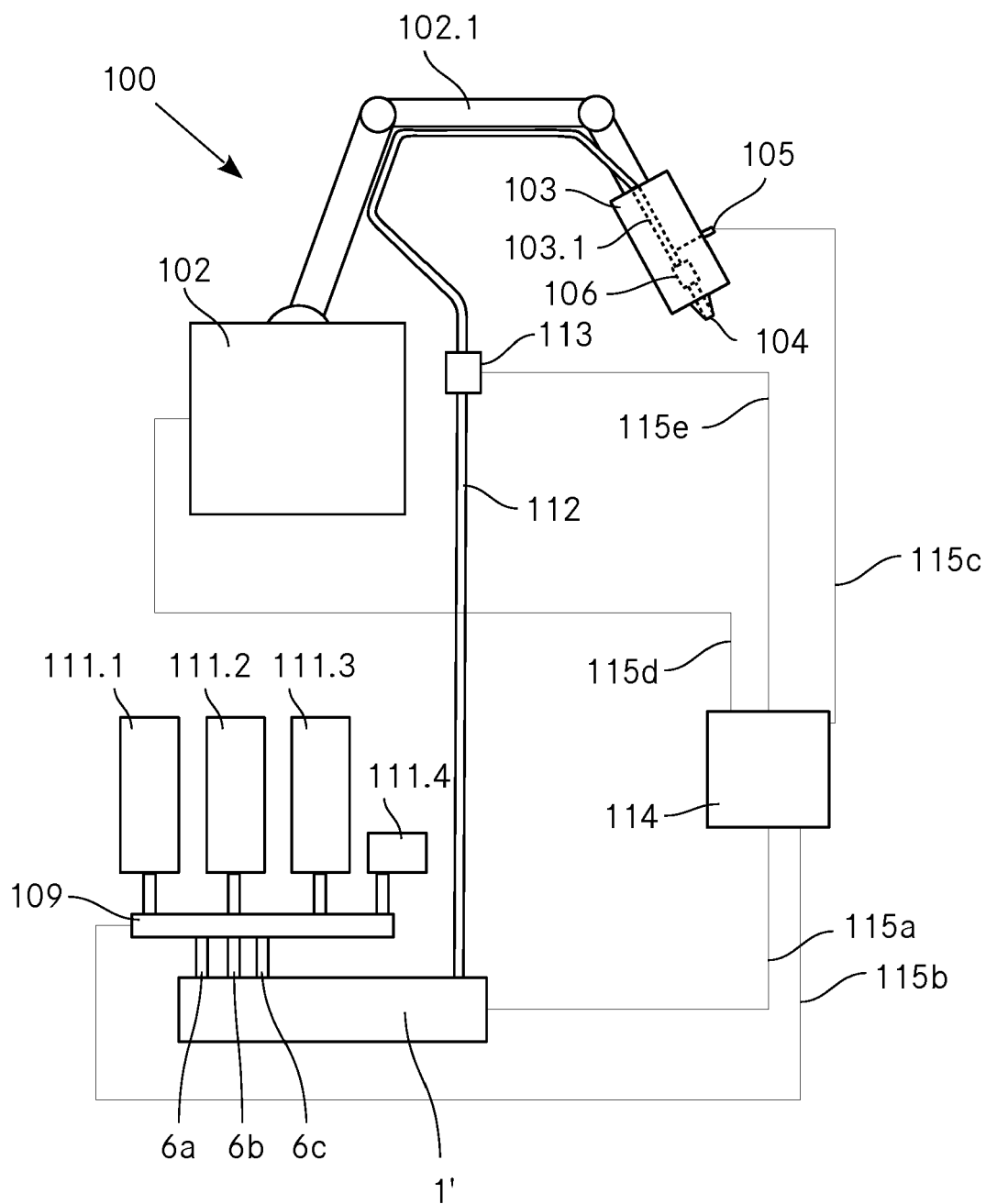


Fig. 3

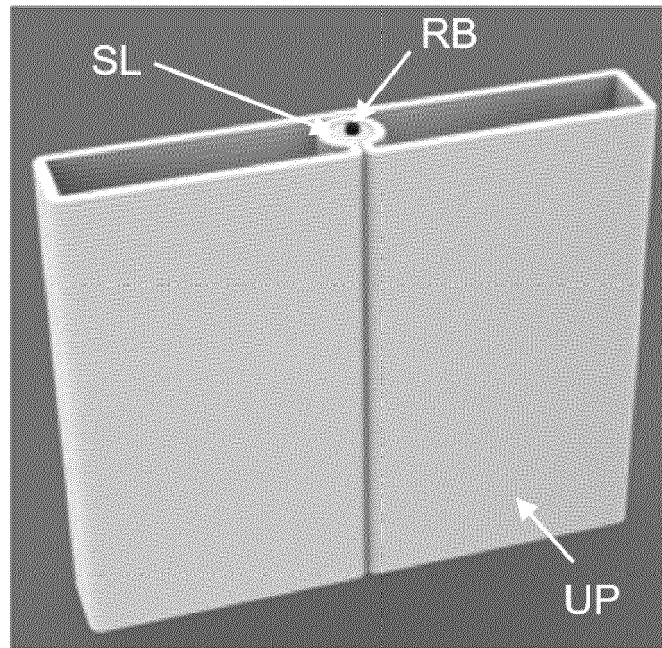


Fig. 4

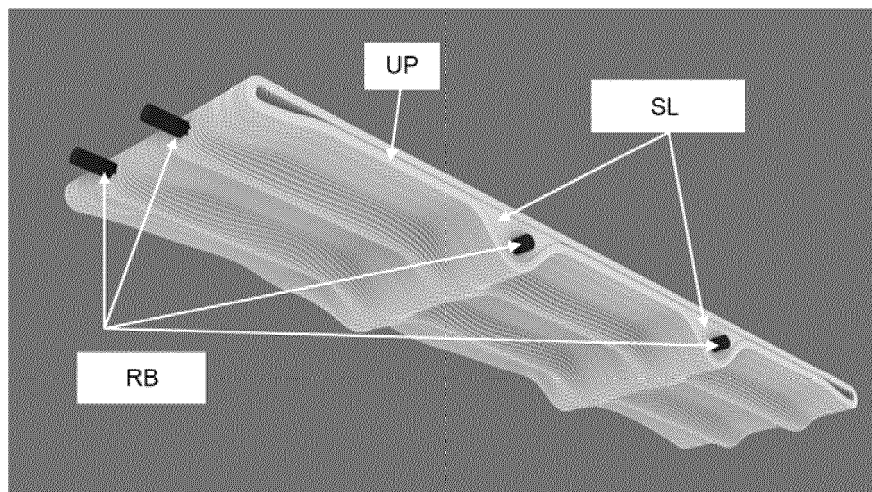


Fig. 5

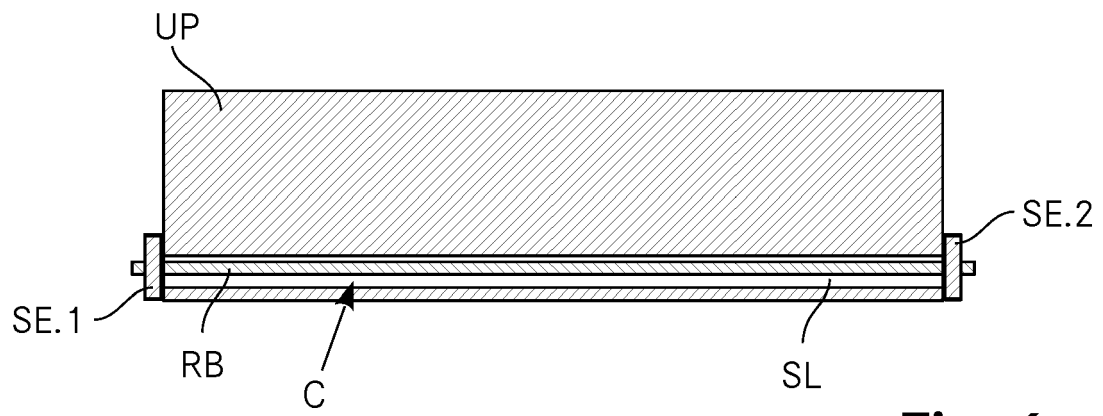


Fig. 6

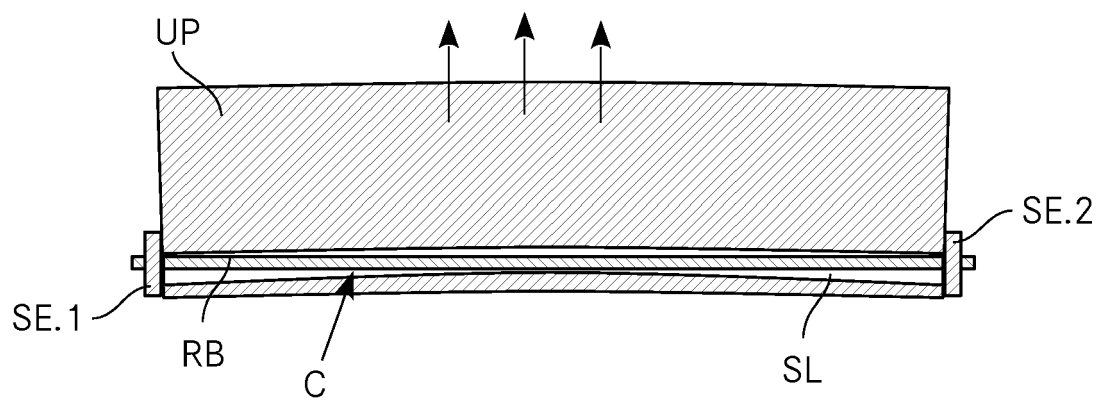


Fig. 7



EUROPEAN SEARCH REPORT

Application Number

EP 22 18 9481

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	AU 2019 407 321 A1 (ZUEBLIN AG [DE]) 24 June 2021 (2021-06-24) * page 2, line 23 - page 3, line 5 * * page 8, line 33 - page 9, line 1 * * page 10, lines 23-31 * * page 11, lines 12-14 * * page 13, lines 4-11, 15-18 * * page 15, lines 27-31 * * figures 1-4 *	1, 2, 7-12, 15	INV. B28B1/00 B28B23/02 B28B23/04
X	US 2019/329447 A1 (ASPRONE DOMENICO [IT] ET AL) 31 October 2019 (2019-10-31) * paragraphs [0001], [0037] - [0039], [0154] * * figures 15, 16 *	1, 2, 7-12, 15	
X	LIM S ET AL: "Developments in construction-scale additive manufacturing processes", AUTOMATION IN CONSTRUCTION, ELSEVIER, AMSTERDAM, NL, vol. 21, 12 June 2011 (2011-06-12), pages 262-268, XP028113945, ISSN: 0926-5805, DOI: 10.1016/J.AUTCON.2011.06.010 [retrieved on 2011-06-17] * page 262, last two lines * * page 265, first paragraph of section 3 * * page 267, first paragraph * * figures 10, 11 *	1, 2, 9-12, 15	TECHNICAL FIELDS SEARCHED (IPC) B28B
X	KR 101 616 308 B1 (UNIV CHOSUN IACF [KR]) 28 April 2016 (2016-04-28) * the whole document *	1, 2, 7-12, 15	
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 10 January 2023	Examiner Papakostas, Ioannis
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number

EP 22 18 9481

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	GB 2 591 831 A (ANDREW ROBERT COWARD [DK]) 11 August 2021 (2021-08-11) * page 15, lines 21-28 * * page 17, lines 19-20 * * figures 7, 13 * -----	1, 3, 9, 11, 12, 15	
A	KR 102 375 456 B1 (UNIV CHUNG ANG IND ACAD COOP FOUND [KR]) 18 March 2022 (2022-03-18) * the whole document * -----	1-3, 7-12, 15	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
Place of search The Hague			Examiner Papakostas, Ioannis
Date of completion of the search 10 January 2023			
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document

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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-3, 7-12, 15

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

**LACK OF UNITY OF INVENTION
SHEET B**

Application Number

EP 22 18 9481

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-3, 7-12, 15

Method for producing a reinforced three-dimensional object from a binder composition with an additive manufacturing process, wherein at least one cavity for receiving a reinforcement element is at least partly formed: (i) while producing an unreinforced three-dimensional object by applying a first curable binder composition with an additive manufacturing device, or (ii) by removing material from the produced, unreinforced, three-dimensional object.

2. claims: 4-6, 13, 14

Method for producing a reinforced three-dimensional object from a binder composition with an additive manufacturing process, wherein both the first and the second curable binder composition comprise the same type of mineral binder and aggregates, differing only in the proportion of water, the nature of an additive and/or a proportion of an additive.

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 22 18 9481

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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