

A CEMENT FORMULA COMPOSITION FOR CONSTRUCTING A MULTIPLE LAYERED OBJECT

FIELD OF INVENTION

- 5 The present invention relates generally to a cement formula composition for constructing a multiple layered object, and more particularly to the construction of objects having non-geometrical shapes.

BACKGROUND

There have been prior attempts in applying 3D printing techniques in the field of
10 construction. Such applications primarily include the method of dispensing the preferred construction material through the printing head's nozzle and depositing the same on one horizontal layer at a time before moving upwards to begin a new layer thereby forming a growing workpiece. The movement is generally under computer control in which the set of instructions related to a desired shape is recorded in the computer memory. A binder is normally incorporated into the
15 material used during the process in order to harden layers. One of the particular techniques is known as extrusion and considered as one of the common 3D printing techniques. However, even within the scope of one particular technique, there are substantial differences when it comes to the selection of materials and the criteria for using the same to achieve the desired shape without compromising the structural strength and integrity.

20 Certain compositions have been disclosed in the prior arts. These include Chinese application No. CN 104230289 A regarding "3D printing composition as well as preparation method and applications thereof." The said prior art discloses a 3D printing composition comprising gypsum powder, gasification enhancer, binding material, enhancer, additives, solid lubricant, and preservatives. However, the said composition is not intended for use in the field of construction,
25 thereby the strength achieved is not sufficiently high.

The other composition has been disclosed as per Chinese application No. CN 104891891A for "3D printing cement-based material and preparation method thereof." The said disclosure refers to 3D printing cement-based materials comprising powdered cementitious material and aggregate. The powdered cementitious material includes cement, superplasticizer, active admixture, early

strength agent, retarding agent, expanders, transfer coagulant, extenders, binders, air-entraining agent, plasticizer, water-repellant agents, starch ethers, powders fillers, and fibers. However, certain limitations are encountered as the said composition suffers from the issue of fast fluidity loss thereby affecting the extrusion performance.

5 It therefore can be seen that the prior arts do not sufficiently address the issue regarding the balance between the hardening behavior of material and the appropriate time for such behavior. Hence, they are not able to support the construction of non-standard structures, particularly in the continuous or semi-continuous extrusion-based construction process. The non-standard structures, in this case, refer to structures having at least one curvature section and/or structures having a non-
10 geometrical shape. Hence, it is necessary to develop a particular formula of the construction material that can be hardened at the appropriate time and the corresponding method of using such material in order to obtain the desired initial setting time and working time for forming such non-standard structures.

15 SUMMARY OF THE INVENTION

 It is therefore the objective of the present invention to provide a cement formula composition that can be used for constructing a multiple layered object having a structural shape that is more flexible when compared to those obtained from the traditional extrusion methods. A cement formula composition for constructing a multiple layered object having at least one
20 referenced layer and an adjacent stacked layer disposed over said referenced layer which are formed by the extrusion of said composition through an extruder head, comprising a hardening accelerator and fibers wherein the amount of said accelerator is in the range of 0.1 to 5 % by weight and comprises an aluminate composition having alumina content in the range of 30 to 98% by weight and wherein the fibers have a length from 0.5 millimeters to half of the diameter of the extruder
25 head and the amount of said fibers is in the range of 0.1 to 1.0% by volume thereby allowing the positions of the outermost edges of the referenced layer and the layer adjacent to have a horizontal overlap based on the relationship that the percentage of said overlap is equal or higher than two times the ratio between the thickness and the width of the referenced layer. In the other aspect, the accelerator can be calcium sulfoaluminate cement (CSA) or high alumina cement (HAC). In the
30 preferred embodiment where HAC is used, it is preferable to have the amount of HAC in the range of 0.1 to 3% by weight.

In the preferred embodiment, in the other aspect, fibers can be one or more fibers selected from a group of polymer fibers such as polypropylene (PP) fiber and polyvinyl alcohol (PVA) fiber, and natural fibers such as refined or unrefined cellulose fiber or chemically treated cellulose fiber, particularly those having low water absorption, and other fiber types such as glass fibers.

5 In the other aspect, the cement formula further comprises at least one or more materials and chemical additives including aggregate, supplementary cementitious material, superplasticizer, retarder, rheology modifier, and water. The aggregate can be selected from a group of sand, limestone, and recycled concrete aggregate. The supplementary cementitious material can also be selected from a group of metakaolin, fly ash, rice husk ash, bottom ash, slag, and silica fume.

10 The objectives and unique characteristics and other aspects of this invention will be described in more detail by way of the examples and drawings included and the best mode will also be further described.

BRIEF DESCRIPTION OF THE DRAWINGS

15 FIG. 1 shows the overlap between layers according to this invention

FIG. 2 shows the measurement of degrees of the constant vertical slope between the positions of the outermost edges of the referenced layer and the other layers of one of the possible embodiments

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

20 For a better understanding of the preferred embodiment and to show how it may be performed, it will now be described in more detail by way of examples only with reference to the accompanying drawings. The parts shown in the drawings will be represented by the referenced number. The description, however, does not imply any limitation, and the scope of the invention will be in accordance with the claims attached herein.

25 According to this invention, a cement formula composition for constructing a multiple layered object having at least one referenced layer and an adjacent stacked layer disposed over said referenced layer which are formed by the extrusion of said composition through an extruder's head, comprising a hardening accelerator and fibers wherein the amount of said accelerator is in the range of 0.1 to 5% by weight and comprises an aluminate composition having alumina content in the

range of 30 to 98% by weight and wherein the fibers have a length from 0.5 millimeters to half of the diameter of the extruder head and the amount of said fibers is in the range of 0.1 to 1.0% in volume thereby allowing the positions of the outermost edges of the referenced layer and the layer adjacent to the said layer to have a horizontal overlap based on the relationship that the percentage of said overlap is equal or higher than two times of the ratio between the thickness and the width of the referenced layer. In the preferred embodiment, the accelerator is HAC and the preferred amount of HAC in the range of is 0.1 to 3% by weight. From the experiment, it was found that the composition without HAC had the initial setting time of 195 minutes (following ASTM C807) and the working time at 25°C and 58% relative humidity of 120 minutes. The addition of HAC reduced the initial setting time and working time to the levels as deemed appropriate for the extrusion. For the addition of HAC using the minimum amount of 0.1%, this would yield the initial setting time of 148 minutes and working time of 110 minutes. For the addition of HAC using the maximum amount of 3%, this would yield the initial setting time of 26 minutes and working time of 16 minutes. However, it should be noted that the appropriate levels may be varied according to the other factors such as the speed of the movement of the nozzle head.

In the preferred embodiment, in the other aspect, fibers can be one or more fibers selected from a group of polymer fibers such as polypropylene (PP) fiber and polyvinyl alcohol (PVA) fiber, and natural fibers such as refined or unrefined cellulose fiber or chemically treated cellulose fiber, particularly those having low water absorption, and other fiber types such as glass fiber or combination of the aforementioned.

Different types of fibers can be used. However, certain amounts are preferred depending on the type of fibers. For example, the amount of PP fiber should be in the range of 0.1 to 0.5% by volume and preferable in the range of 0.1 to 0.2% by volume. The amount of PVA fibers should be in the range of 0.1 to 0.6% by volume and preferable in the range of 0.1 to 0.3% by volume. The amount of chemically treated cellulose fiber, particularly those having low water absorption should be in the range of 0.1 to 0.5% by volume and preferably in the range of 0.1 to 0.2% by volume. The amount of glass fiber should be in the range of 0.1 to 0.5% by volume and preferable in the range of 0.1 to 0.2% by volume. From the experiment, the addition of fibers significantly increased the yield stress of each layer. The said addition also increased the extension distance before the layer yielded in a flexural test.

The preferred cement formula further comprises at least one or more materials and chemical additives including aggregate, supplementary cementitious material, superplasticizer, retarder, rheology modifier, and water. The aggregate can be selected from a group of sand, limestone, and recycled concrete aggregate. The supplementary cementitious material can also be selected from a group of metakaolin, fly ash, rice husk ash, bottom ash, slag, and silica fume.

Different types of aggregate can be used. These include sand, limestone, and recycled concrete aggregate. Certain amounts of such aggregate are also preferred based on the type of aggregate. In case that sand is selected, the amount of sand should be in the range of 0.1 to 60% by weight. In case that limestone is selected, the amount of limestone should be in the range of 20 to 70% by weight and is preferable to be in the range of 35 to 60% by weight. In case that recycled concrete aggregate is used, the amount of recycled concrete aggregate should be in the range of 0.1 to 50% by weight and is preferable to be in the range of 0.1 to 50% by weight.

Different types of supplementary cementitious material can also be used. These include metakaolin, fly ash, rice husk ash, bottom ash, slag, and silica fume. If metakaolin is used, the amount of metakaolin should be in the range of 0.1 to 8% by weight. If fly ash, rice husk ash, and bottom ash are used, the amount of ash should be in the range of 4 to 10% by weight. If slag is used, the amount of slag should be in the range of 6 to 8% by weight. In case that silica fume is used, the amount of silica fume should be in the range of 2 to 10% by weight and is preferable to be in the range of 3 to 5% by weight.

The amount of superplasticizer should be in the range of 0.1 to 0.2% by weight. The amount of retarder should be in the range of 0.01 to 0.05% by weight and is preferable to be in the range of 0.01 to 0.02% by weight. The amount of rheology modifier should be in the range of 0.1 to 0.5% by weight and is preferable to be in the range of 0.1 to 0.3% by weight. The amount of water should be in the range of 8 to 20% by weight and is preferable to be in the range of 9 to 15% by weight.

One may use the composition according to this invention by providing a chamber containing a cement composition; dispensing said cement composition from the said chamber; consolidating cement composition into a first layer to form a first cross-section of the object; dispensing a cement composition onto the said first layer and repeating the consolidation to form a second cross-section of said object; Repeating the dispensing, consolidating steps to build a successive layers in a layer-wise fashion in accordance with said design for forming a multiple layered object. During such process, it is important to control the consolidation of said composition by measuring the speed of

the movement of the dispenser and the time against the predefined threshold and controlling stability of the layered construction.

The said control of the stability includes the monitor of horizontal difference between the positions of the outermost edges of the referenced layer and the layer adjacent based on the relationship that the percentage of said difference is equal or higher than two times the ratio between the thickness and the width of the referenced layer. The said arrangement can be described using the formula:

$$\% \text{ of Overlap} \times \left(\frac{\text{Width}}{\text{Thickness}} \right) \geq 2.0$$

FIG. 1 shows the overlap between layers according to the aforementioned formula.

One of the significant technical effects is that, by overlapping layers based on the criteria as described in this disclosure, the acceptable level of compressive strength can still be achieved. This provides a level of flexibility for construction that cannot be expected from the traditional extrusion method without the cement formula composition according to this present invention. From the experiments, a non-geometrical shape having different levels of the slope between the upper and lower layers was constructed. It was found from the said experiments that the vertical slope measuring from the positions of the outermost edges of the referenced layer and the layer adjacent to the said layer can be varied from less than 90 degrees to 50 degrees. It is easier to demonstrate the flexibility of the arrangement when the slopes between different pairs of layers are constant. A sample of which is shown in FIG. 2. However, this sample does not in any way limit the possibility to position layers having inconsistent vertical slope.

Four examples of the invention are shown below, which are not intended to limit the invention. In the examples, “%” means a weight basis unless otherwise specified. The amount of HAC and fibers are varied within the ranges specified according to this invention. The desired effects including setting time and compressive strength that correspond to each example are also shown below.

Material	Example 1	Example 2	Example 3	Example 4
Ordinary Portland Cement	28.00%	28.00%	26.50%	25.00%
HAC	0.00%	0.00%	1.50%	3.00%
Fly ash	8.00%	8.00%	8.00%	8.00%
Silica fume	4.00%	4.00%	4.00%	4.00%
Limestone	60.00%	60.00%	60.00%	60.00%
Sum	100.00%	100.00%	100.00%	100.00%
Superplasticizer	0.12%	0.12%	0.13%	0.10%
Retarder	0.01%	0.01%	0.01%	0.01%
Fiber having the length in the range of 3 to 6 mm (% by volume)	0.00%	0.20%	0.20%	0.20%
Shot fiber having the length less than 1mm (% by volume)	0.00%	0.20%	0.10%	0.25%
Total	100.13%	100.53%	100.44%	100.56%

Compressive strength (MPa)	Example 1	Example 2	Example 3	Example 4
1-Day	37.8	32.6	34.1	34.3
3-Day	61.1	49.2	56.7	58.5
7-Day	72.7	53.6	58.8	60.6
28-Day	76.0	59.9	70.2	68.1
Initial setting time (min)	195	195	35	26
Working time (min)	120	120	35	16

Extension of 3-point bending (mm)	Example 1	Example 2	Example 3	Example 4
1-Day	0.4	3.0	3.0	3.0
3-Day	0.6	2.4	2.2	2.4

Yield stress (10^{-4} Pa)	61.8	102	102	103
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Percentage of an overlap * (width / thickness)	Number of layers			
	Example 1	Example 2	Example 3	Example 4
2.16	2	2	8	not collapse
2.42	5	12	not collapse	not collapse
2.64	10	30	not collapse	not collapse

It will be appreciated by persons skilled in the art that the present inventions are not limited by what has been particularly shown described hereinabove. Rather the scope of the present invention includes both combinations and sub-combinations of the features described hereinabove as well as modifications and variations thereof which would occur to a person of skill in the art upon reading the foregoing description and which are not in the prior art.

CLAIMS

- 1) An extrudable cement formula composition, comprising a hardening accelerator and fibers, characterized in that said accelerator is calcium sulfoaluminate provided in an amount in the range of 0.1% to 5% by weight with an aluminate composition having alumina content in the range of 30% to 98% by weight, and the amount of said fibers is in the range of 0.1% to 1.0% by volume, and said fibers comprises a fiber population of length in the range of 3 to 6 mm and another fiber population of length less than 1 mm.
- 2) The extrudable cement formula composition of claim 1 wherein the fiber length ranges from 0.5 mm to 6 mm.
- 3) The extrudable cement formula composition of claim 1 wherein said fibers includes polymer fibers, natural fibers, glass fibers, and combinations thereof.
- 4) The extrudable cement formula composition of claim 1, further comprising at least one or more of the materials and chemical additives selected from a group consisting of aggregate, supplementary cementitious material, superplasticizer, retarder, rheology modifier, and water.
- 5) The extrudable cement formula composition of claim 4 wherein the aggregate is one or more aggregates selected from a group consisting of sand, limestone, and recycled concrete aggregate.
- 6) The extrudable cement formula composition of claim 4, wherein the supplementary cementitious material is selected from a group consisting of metakaolin, fly ash, rice husk ash, slag and silica fume.
- 7) Method of using the extrudable cement formula composition according to each one claims 1-6 for constructing a multiple layered object having at least one referenced layer and an adjacent stacked layer disposed over said referenced layer which are formed by the extrusion of said composition through an extruder head, characterized in that it comprises the following steps:
 - a) providing a chamber containing said cement composition;
 - b) dispensing said cement composition from said chamber;
 - c) consolidating cement composition into a first layer to form a first cross-section of the object;

d) dispensing a cement composition onto the said first layer and repeating the consolidation to form a second cross-section of said object;

e) repeating the dispensing, consolidating steps to build a successive layers in a layer-wise fashion in accordance with said design for forming a multiple layered object,

wherein during the process:

the consolidation of said composition is controlled by measuring the speed of the movement of the dispenser and the time against the predefined threshold, and

the stability of the layered construction is controlled monitoring the horizontal difference between the positions of the outermost edges of the referenced layer and the layer adjacent based on the relationship :

Percentage of Overlap (%) X (Width/Thickness) $\geq$ 2.0,

wherein the percentage of said overlap is equal or higher than two times the ratio between the thickness and the width of the referenced layer.

8) Method according to claim 7 characterized in that the vertical slope measuring from the positions of the outermost edges of the referenced layer and the layer adjacent to said layer can be varied from less than 90 degrees to 50 degrees.