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MAGNETIC STEREOLITHOGRAPHY PRINT HEAD, STEREOLITHOGRAPHY PRINTER, AND METHOD OF STEREOLITHOGRAPHY PRINTING

Abstract

An apparatus, including: a print head (124) including: an attachment (126) that is configured to be attached to a movable carriage of a stereolithography 3D printer (SLA printer); and when the print head is installed on the movable carriage: a build platform (202) having a bottom surface (146) that faces downward, a front surface (162) that faces a front of the SLA printer, a rear surface (166) that faces a rear of the SLA printer, and side surfaces (174, 176) connecting the front surface to the rear surface; and at least one magnet (152) secured to the print head.

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Background/Summary

FIELD OF THE INVENTION

[0001] The invention relates to a stereolithography printer having a print head that aligns magnetic particles in a resin composition used to print a layer.

BACKGROUND

[0002] In a stereolithography 3D printer (SLA printer), a print head is lowered onto a photosensitive resin or resin composition in a reservoir. A layer of the resin is selectively irradiated with light. The selectively irradiated parts of the layer of resin solidify onto the print head in response to the irradiation. The layer forms one layer of many layers of a component. The print head is raised by a thickness of the layer and the process is repeated on the prior layer until all the layers of the component are so formed.

[0003] There are instances when it is desirable for the resin to be a resin composition having particles suspended therein. There are also instances when it is desirable for the particles to be oriented in a particular direction for a variety of reasons. Particles that are aligned along a particular direction may, for example, result in a layer that is stronger in tension along the particular direction. Such a layer may also mitigate crack propagation in directions transverse to the particular direction.

[0004] Prior art SLA printers propose various schemes for accomplishing this. One method disposes magnetically response particles in the resin composition and aligns the magnetically responsive particles by applying a magnetic field to the area of the resin composition being irradiated when printing the layer. However, these are understood to be complex arrangements that may not be fully developed. Hence, there is room in the art for improvement.

SUMMARY

[0005] In a first example embodiment, the disclosure provides a print head with: an attachment that is configured to be attached to a movable carriage of a stereolithography 3D printer (SLA printer); and when the print head is installed on the movable carriage: a build platform comprising a bottom surface that faces downward, a front surface that faces a front of the SLA printer, a rear surface that faces a rear of the SLA printer, and side surfaces connecting the front surface to the rear surface. The print head further includes at least one magnet secured to the print head.

[0006] In a second example embodiment, disclosed is a stereolithography 3D printer having the print head disclosed herein.

[0007] In a third example embodiment, disclosed is a method of SLA printing that includes: positioning the print head of the SLA printer onto a resin composition, wherein the resin composition comprises magnetically responsive particles; aligning the magnetically responsive particles in the resin composition with a magnetic field generated by the at least one magnet; and SLA printing the resin composition comprising the magnetically responsive particles to form a solid layer comprising aligned magnetically responsive particles.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention is explained in the following description in view of the drawings that show:

[0009] FIG. **1** is a schematic illustration of a stereolithography (SLA) printer arrangement.

[0010] FIG. **2** and FIG. **3** are schematic illustrations of an example embodiment of a print head of the SLA printer of FIG. **1**.

[0011] FIG. **4** through FIG. **9** are schematic illustrations of various example embodiments of the print head of the SLA printer of FIG. **1**.

[0012] FIG. **10** is a flow chart describing an example embodiment of a method of SLA printing.

[0013] FIG. **11** is a flow chart describing an example embodiment of a method of optimizing a printer to print using the method of FIG. **10**.

[0014] FIG. **12** is a flow chart describing an example embodiment of a method of optimizing resin composition used to print using the method of FIG. **10**.

DETAILED DESCRIPTION

[0015] The present inventors have devised a unique and innovative print head and associated SLA printer that enables alignment of magnetically responsive particles in a resin composition when printing a layer of the resin composition. The print head is simple and inexpensive, and the principle can be used with a variety of different SLA printers and print heads. The inventors have also developed a resin composition suitable for such printing. In addition, the inventors have identified certain parameters that can be adjusted to optimize printing with the print head and resin compositions.

[0016] FIG. **1** is a schematic illustration of a stereolithography (SLA) printer arrangement **100** including an SLA printer **102** and an optional computer **104** in data communication **106** with a controller **108** in the SLA printer **102** and through which parameters of the SLA printer **102** can be adjusted. The SLA printer **102** has an interface **110** through which the parameters can also be adjusted.

[0017] The SLA printer **102** includes, inter alia, a track **120** along which a moveable carriage **122** can translate vertically, and a print head **124**. The print head **124** includes an attachment **126** that connects to an associated receiver **128** on the moveable carriage **122**. As such, the print head **124** moves vertically with the moveable carriage **122**. The SLA printer **102** further includes a reservoir **140** that may be transparent and a light arrangement **142** configured to selectively irradiate a resin composition **144** disposed in the reservoir **140**.

[0018] During SLA printing, a bottom surface **146** of the print head **124** is lowered onto the surface of the resin composition **144**. The light arrangement **142** selectively irradiates a layer of the resin composition adjacent the print head **124**. This irradiation solidifies the selectively irradiated portions of the layer which adhere to the bottom surface **146**. This completes one layer of a print job. The next layer is printed by raising the print head **124** by the thickness of the just-printed layer so the bottom of the just-printed layer rests on the resin composition. The light arrangement **142** again selectively irradiates another layer of the resin composition adjacent the bottom of the just-printed layer. This irradiation solidifies the selectively irradiated portions of the other layer which adhere to the bottom of the just-printed layer, thereby completing the second layer of the print job. This process is repeated until all layers of the print job are completed. For each print job, there may be a first layer, a burn in layer, and several model layers. Each model layer represents a respective layer of the component.

[0019] The SLA printer **102** disclosed herein is configured to align magnetically responsive particles **150** suspended in the resin composition **144** during the print process. To do this, at least one magnet **152** is secured to the print head **124**. The at least one magnet **152** generates a magnetic field **154** capable of aligning the magnetically responsive particles **150** in the resin composition **144** when the bottom surface **146** of the print head **124** rests on the resin composition. This alignment is maintained during the printing process because the magnetic field is applied

throughout the print process. Consequently, when the light arrangement **142** selectively irradiates and solidifies the layer of resin composition **144**, the magnetically responsive particles disposed in the resin composition **144** and aligned with the magnetic field **154** maintain their orientation as they become part of the solidified layer.

[0020] The at least one magnet **152** may be a permanent magnet, an electromagnet, or a combination thereof. In an example embodiment, the at least one magnet **152** is an N52 type magnet. An N52 magnet is a neodymium magnet grade with an energy product or BHMax of 52 Mega-Gauss Oersteds. In the example embodiment, this type of magnet provides a proper balance between generating a magnetic field **154** that is strong enough to align the magnetically responsive particles **150** but not too strong. Magnetic fields that are too strong may interfere with electronics associated with the SLA printer **102** and/or may tend to draw the magnetically responsive particles **150** up from the resin composition **144**.

[0021] In the embodiment shown, the at least one magnet **152** includes at least one front magnet **160** disposed on a front surface **162** of the print head **124** and at least one rear magnet **164** disposed on a rear surface **166** of the print head **124**. The front surface **162** faces a front **170** of the SLA printer. The rear surface **166** faces a rear **172** of the SLA printer **102**. Side surfaces **174**, **176** connect the front surface **162** to the rear surface **166**.

[0022] FIG. 2 is an exploded schematic illustration of an example embodiment of a print head **124** of the SLA printer **102** of FIG. 1. In this example embodiment, the print head **124** includes a print head body **200**, a build platform **202** that defines the bottom surface **146**, two front magnets **160**, and two rear magnets **164**. The build platform **202** may be secured to the print head body **200** via fasteners **204**. The print head body **200** may be solid or hollow. If hollow, the print head body **200** may interfere less with the magnetic field **154** generated by the at least one magnet **152**.

[0023] FIG. 3 is a schematic illustration of an example embodiment of a print head **124** of FIG. 2 in an assembled condition.

[0024] FIG. 4-FIG. 9 are schematic illustrations of various example embodiments of the print head of the SLA printer of FIG. 1. In the example embodiment of FIG. 4, there are two front magnets **160** that are evenly spaced and two rear magnets **164** that are evenly spaced. In this example embodiment, the north poles (N) and the south poles (S) are all positioned the same way. In this example embodiment, the front magnets **160** are adhered to the front surface **162** using an adhesive. An example adhesive, not meant to be limiting, is cyanoacrylate. In this example embodiment, the rear magnets **164** are secured to the print head **124** via a releasable connection **400**. The releasable connection **400** includes a first half **402** and a second half **404** that releasably secured to the first half **402**. An example releasable connection could be a hook and loop connection such as Velcro®. Another example includes double sided tape. The releasable connection **400** can be configured such that the first half **402** is a strip/patch that is larger than actually needed to secure the rear magnets **164** in the selected positions. Each second half **404** is simply as large as needed to secure a respective rear magnet **164** to the first half **402**. Because the first half **402** covers a large portion or all of the rear surface **166**, the rear magnets **164** can be removed from the position shown and repositioned as desired anywhere along the rear surface **166**. The releasable connection **400** can be used for any magnet or magnets of the at least one magnet **152**.

[0025] In the example embodiment of FIG. 5, there are three front magnets **160** that are evenly spaced and three rear magnets **164** that are evenly spaced. In the example embodiment of FIG. 6, there are three front magnets **160** that are unevenly spaced and three rear magnets **164** that are evenly spaced. In this example embodiment, two of the front magnets **160** are stacked on each other. Two or more magnets can be stacked in any location and pattern. The number of magnets in each stack can be the same or different from the number in another stack.

[0026] In the example embodiment of FIG. 7, two side magnets **700** are evenly spaced on the side surface **174**, and two side magnets **702** are evenly spaced on the side surface **176**. In the example

embodiment of FIG. 8, at least two bottom magnets **800** are disposed evenly about a top surface **802** of the build platform **202**. In the example embodiment of FIG. 9, magnets **900** are disposed on the side surface of the attachment **126**.

[0027] Additional embodiments include any combination of any of the aspects of the above embodiments. For example, some magnets may be evenly spaced and some not. Also, magnets may be disposed on any combination of sides or the connector etc. The configuration chosen for the magnets depends on the field lines desired by the user. The embodiment of FIG. 4, for example, is optimized for maximum distance length of aligned particles in the x direction to the print head **124**. Stacking magnets allows for intermediate field strength, thereby providing for configurations in which the field strength can also be tailored.

[0028] FIG. 10 is a flow chart describing an example embodiment of a method of SLA printing. The method includes: **1000** positioning the print head **124** of the SLA printer **102** onto the resin composition **144**, wherein the resin composition **144** comprises magnetically responsive particles **150**; **1002** aligning the magnetically responsive particles **150** in the resin composition **144** with a magnetic field **154** generated by the at least one magnet **152**; and **1004** SLA printing the resin composition **144** comprising the magnetically responsive particles **150** to form a solid layer comprising aligned magnetically responsive particles.

[0029] To aid in achieving the above SLA printing method, the SLA printer **102** may be optimized for use with the print head **124**. In an example embodiment, not meant to be limiting, parameters for an Autodesk Ember 3D printer were optimized. FIG. 11 is a flow chart describing an example embodiment of a method of optimizing the SLA printer **102** to print using the method of FIG. 10. The method includes: **1100** print using factory settings for the parameters; **1102** determining if the print is acceptable; if yes, the optimization is complete **1104**; if no, **1106** the parameters are adjusted. While all of the parameters may be adjusted to achieve optimized printing, adjustments of certain targeted parameters may expedite optimization. These parameters include: wait before exposure time; exposure time; separation slide velocity; and approach velocity. These parameters may be the same across all layer types, or they may be unique for each layer type.

[0030] In an example embodiment using the Autodesk Ember 3D printer, when the solid layer is a first layer, the SLA printing is characterized by: a separation slide velocity of from 0.5 to 1 rpm, and in an example embodiment of 1.0 rpm; and approach slide velocity of from 0.5 to 1 rpm, and in an example embodiment of 1.0 rpm. When the solid layer is a burn in layer, the SLA printing is characterized by: an exposure time of from 5 to 10 seconds depending on the specifics of the equipment and the resin composition, and in an example embodiment of 8.0 seconds; a separation slide velocity of from 0.5 to 1 rpm, and in an example embodiment of 1.0 rpm; and approach slide velocity of from 0.5 to 1 rpm, and in an example embodiment of 1.0 rpm. When the solid layer is a model layer, and wherein the SLA printing is characterized by: a wait before exposure time of from 3 to 10 seconds, and in an example embodiment of 5.0 seconds; an exposure time of from 5 to 10 seconds, and in an example embodiment of 6.0 seconds; a separation slide velocity of from 1 to 2 rpm, and in an example embodiment of 2.0 rpm; and approach slide velocity of between 2 and 4 rpm, and in an example embodiment of 3.0 rpm. While these settings are suitable for the printer of the example embodiment, other printers may require individualized optimization.

[0031] To further aid in achieving the above SLA printing method, the resin composition **144** may be optimized for use in the SLA printer **102**. In the example embodiment, not meant to be limiting, the resin composition **144** composition was optimized for an Autodesk Ember 3D printer. In the example embodiment, the magnetically responsive particles **150** in the resin composition **144** are iron oxide Fe₃O₄. However, any magnetically responsive material can be used for the magnetically responsive particles **150**. For example, other suitable magnetically responsive particles **150** include magnetite (Fe₃O₄), maghemite (γ-Fe₂O₃), as well as other magnetic alloys including CoFe, or other nickel or cobalt alloys.

[0032] FIG. 12 is a flow chart describing an example embodiment of a method of optimizing resin

composition **144** used to print using the method of FIG. **10**. The method includes printing with a 10 weight % Fe₃O₄. While 10 weight % Fe₃O₄ is used as a starting point in this example, any percentage can be used as the starting point. If **1202** the print is not too opaque, and **1204** if the lines in the print can be differentiated from a control (non-aligned print), then **1206** the composition is optimized. In an example embodiment, the control print is simply a print made using a regular (without magnets) print head **124**. If **1202** the print is too opaque, then **1208** the weight % Fe₃O₄ can be reduced and reprinted until the print is not too opaque. If **1204** the print is not too opaque, but the lines cannot be differentiated from a control (non-aligned print), then the weight % Fe₃O₄ can be increased and reprinted until the print is both not too opaque and the lines can be differentiated. In the example embodiment, the resin composition **144** comprises a weight % Fe₃O₄ of between 0.2 and 1.0. In the example embodiment, the resin composition **144** comprises a weight % Fe₃O₄ of between 0.4 and 0.8. In the example embodiment, the resin composition **144** comprises a weight % Fe₃O₄ of 0.6. While these ranges are suitable for the printer of the example embodiment, other printers may require individualized optimization of the resin composition **144**. [0033] The inventors have developed a print head that can be used with a variety of SLA printers and which can print composite resins in which magnetically responsive materials are directionally aligned. The solution is simple, inexpensive, and reliable, and therefore represents an improvement in the art. In addition, the principles discussed above can be readily applied to print heads of different printers.

[0034] While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, swapping of features among embodiments, changes, and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

Claims

1. A method, comprising: positioning the print head of the SLA printer of claim **12** onto a resin composition, wherein the resin composition comprises magnetically responsive particles; aligning the magnetically responsive particles in the resin composition with a magnetic field generated by the at least one magnet; and SLA printing the resin composition comprising the magnetically responsive particles to form a solid layer comprising aligned magnetically responsive particles.
 2. The method of claim 1, wherein the solid layer comprises a first layer, and wherein the SLA printing is characterized by: a separation slide velocity of from 0.5 to 1 rpm; and approach slide velocity of from 0.5 to 1 rpm.
 3. The method of claim 1, wherein the solid layer comprises a burn in layer, and wherein the SLA printing is characterized by: an exposure time of from 5 to 10 seconds; a separation slide velocity of from 0.5 to 1 rpm; and approach slide velocity of from 0.5 to 1 rpm.
 4. The method of claim 1, wherein the solid layer comprises a model layer, and wherein the SLA printing is characterized by: a wait before exposure time of from 3 to 5 seconds; an exposure time of from 5 to 10 seconds; a separation slide velocity of from 1 to 2 rpm; and approach slide velocity of from 2 to 4 rpm
 5. The method of claim 1, wherein the resin composition comprises a weight % Fe₃O₄ of between 0.2 and 1.0.
 6. The method of claim 5, wherein the weight % Fe₃O₄ is between 0.4 and 0.8.
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