these functions is disclosed in U.S. Patent Application Publication 2019/0315057 that published on October 17, 2019 (“the ’057 publication”).

[0005] While the print head of the ’057 publication may be functionally adequate for many applications, it may be less than optimal. For example, the print head may lack accuracy in placement, cutting, compaction, and/or curing that is required for other applications. The disclosed print head and system are directed at addressing one or more of these issues and/or other problems of the prior art.

Summary

[0006] In one aspect, the present disclosure is directed to a system for additively manufacturing a composite structure. The system may include a support, and a print head operatively connected to and moveable by the support. The print head may include a supply of continuous reinforcement, an outlet configured to discharge the continuous reinforcement, and a tensioning module disposed between the supply and outlet. The tensioning module may be configured to generate a signal indicative of at least one of a tension in the continuous reinforcement and a position of the tensioning module. The tensioning module may include a swing arm, first and second redirects located at first and second ends of the swing arm. The first and second redirects may be configured to receive the continuous reinforcement. The first redirect may be located upstream of the second redirect relative to travel of the continuous reinforcement through the print head. The tensioning module may further include a pivot coincident with the first redirect, and a rotary sensor. The rotary sensor may be configured to generate the signal during pivoting of the swing arm about the pivot. The system may also include a processor programmed to selectively cause the supply to dispense the continuous reinforcement based on the signal.

[0006a] In another aspect, the present disclosure is directed to a method for controlling tension in a continuous reinforcement of an additive manufacturing system. The system may include a support and a print head operatively connected to and moveable by the support. The print head may include a supply of continuous reinforcement, an outlet configured to discharge the continuous reinforcement, and a tensioning module disposed between the supply and outlet. The tensioning module may be configured to generate a signal indicative of at least one of a tension in the continuous reinforcement and a position of the tensioning module. The tensioning module may include a swing arm and first and second redirects located at first and second ends of the swing arm. The first and second redirects may be configured to receive the continuous reinforcement. The first redirect may be located upstream of the second redirect relative to travel of the continuous reinforcement through the print head. The tensioning module may

further include a pivot coincident with the first redirect and a rotary sensor. The rotary sensor may be configured to generate the signal during pivoting of the swing arm about the pivot. The method may further include receiving, by a processor, the signal, and selectively causing, by the processor, the supply to dispense the continuous reinforcement based on the signal.

[0006b] In yet another aspect, the present disclosure is directed to a computer program product. The computer program product may include computer program code configured, when executed on a computer processor, to undertake a method in relation to an additive manufacturing system. The system may include a support and a print head operatively connected to and moveable by the support. The print head may include a supply of continuous reinforcement, an outlet configured to discharge the continuous reinforcement, and a tensioning module disposed between the supply and outlet. The tensioning module may be configured to generate a signal indicative of at least one of a tension in the continuous reinforcement and a position of the tensioning module. The tensioning module may include a swing arm and first and second redirects located at first and second ends of the swing arm. The first and second redirects may be configured to receive the continuous reinforcement. The first redirect may be located upstream of the second redirect relative to travel of the continuous reinforcement through the print head. The tensioning module may further include a pivot coincident with the first redirect and a rotary sensor. The rotary sensor may be configured to generate the signal during pivoting of the swing arm about the pivot. The method may include receiving, by a processor, the signal, and selectively causing, by the processor, the supply to dispense the continuous reinforcement based on the signal.

[0007] In an example, the present disclosure is directed to a method of additively manufacturing a composite structure. The method may include directing a continuous reinforcement from a supply of a print head to an outlet, and generating a signal indicative of a tension in the continuous reinforcement at a location between the supply and the outlet. The method may also include selectively causing the supply to dispense the continuous reinforcement based on the signal.

[0008] In one example, the method further includes wetting the continuous reinforcement with a matrix at a location inside of the print head, and discharging the wetted continuous reinforcement through the outlet, wherein generating the signal includes generating the signal indicative of a tension at the location.

[0009] In one example, the method further includes pivoting a swing arm with the continuous reinforcement, wherein generating the signal includes generating the signal based on the pivoting.

[0010] In one example, the method further includes counterbalancing the swing arm and biasing the swing arm toward a low-tension position.

[0011] In another example, the present disclosure is directed to another additive manufacturing system. This system may include a support, and a print head operatively connected to and moveable by the support. The print head may include a first supply configured to hold a continuous reinforcement, a second supply configured to hold a matrix separate from the continuous reinforcement, and a wetting mechanism in separate communication with the first and second supplies and configured to discharge the continuous reinforcement wetted with the matrix. A controller may be programmed to selectively pressurize the second supply to direct the matrix to the wetting mechanism.

[0012] In one example, the wetting mechanism is located remotely from the second supply and communicated with the second supply via a conduit.

[0013] In one example, the print head further includes a sensor associated with the wetting mechanism. The controller may be programmed to pressurize the second supply based on a signal from the sensor in a feedback manner.

[0014] In one example, the sensor is a pressure sensor configured to generate the signal in response to a pressure inside the wetting mechanism.

[0015] In one example, the controller is programmed to pressurize the second supply based further on a feed rate of the continuous reinforcement through the wetting mechanism in a feedforward manner.

[0016] In one example, the print head further includes a heating element configured to heat the matrix in at least one of the second supply and the wetting mechanism.

[0017] In one example, the second supply is configured to receive a cartridge containing the matrix.

[0018] In one example, the cartridge includes a piston moved by the pressure to push matrix out of the second supply.

[0019] In one example, the print head further includes a sensor configured to detect a position of the piston and direct a corresponding signal indicative of an amount of matrix remaining in the cartridge to the controller.

[0020] In one example, the controller is programmed to selectively communicate a pressurized medium with the piston to selectively pressurize the second supply.

[0021] In one example, the second supply includes a vessel having an open end configured to receive the cartridge, and a cap configured to close off the open end of the vessel.

[0022] In one example, the print head further includes a bracket connecting the vessel to a housing of the print head.

[0023] In one example, the cartridge includes a flexible membrane that collapses as matrix is pushed from the cartridge.

[0024] In one example, the flexible membrane is configured to block energy that triggers curing of the matrix.

[0025] In one example, the flexible membrane is at least partially transparent.

[0026] In one example, the print head further includes a metering valve disposed between the second supply and the wetting mechanism.

[0027] In another example, the present disclosure is directed to another method of additively manufacturing a composite structure. This method may include directing a continuous reinforcement from a first supply on a print head to a wetting mechanism, and selectively pressurizing a second supply on the print head to push a liquid matrix from the second supply to the wetting mechanism. The method may also include wetting the continuous reinforcement with the liquid matrix in the wetting mechanism, and discharging the wetted continuous reinforcement through an outlet of the print head.

[0028] In one example, the method further includes sensing a pressure of the liquid matrix in the wetting mechanism, wherein selectively pressurizing the second supply includes selectively pressurizing the second supply based on the sensed pressure.

[0029] In one example, the method further includes heating the liquid matrix in at least one of the second supply and the wetting mechanism.

[0030] In one example, selectively pressurizing the second supply causes the liquid matrix to be pushed from a cartridge. In this example, the method further includes generating a signal indicative of a volume of liquid matrix remaining in the cartridge, and selectively replacing the cartridge based on the signal.

[0031] In another example, the present disclosure is directed to another additive manufacturing system. This system may include a support, and a print head operatively connected to and moveable by the support. The print head may include an outlet configured to discharge a material in a trajectory along a central axis of the outlet, and a compactor disposed downstream

of the outlet relative to the trajectory and configured to press the material transversely against an adjacent surface. The outlet may be configured to translate relative to the compactor.

[0032] In one example, the outlet is configured to translate in a direction aligned with the central axis.

[0033] In one example, the compactor is configured to roll over the material.

[0034] In one example, the outlet is part of a wetting module that separately receives a continuous reinforcement and a matrix and discharges the continuous reinforcement wetted with the matrix as the material.

[0035] In one example, the outlet is a tip of a nozzle at a downstream end of the wetting module.

[0036] In one example, the print head further includes a clamp located upstream of the wetting module and configured to selectively clamp the continuous reinforcement before the continuous reinforcement is wetted with the matrix. The clamp may translate with the wetting module.

[0037] In one example, the print head further includes a clamp located upstream of the outlet and configured to selectively clamp the material. The clamp may translate with the outlet.

[0038] In one example, the compactor is configured to extend and retract during pressing against the material.

[0039] In one example, a translation direction of the outlet is oriented at an oblique angle relative to an extension-retraction direction of the compactor.

[0040] In one example, the oblique angle is 30-60°.

[0041] In one example, the oblique angle is 45°.

[0042] In one example, the print head further includes a cutting module configured to translate together with extension and retraction of the compactor.

[0043] In one example, the cutting module is additionally configured to translate relative to the compactor in a same direction as the extension and retraction of the compactor.

[0044] In one example, the system further includes a controller programmed to selectively cause translation of the outlet, translation of the cutting module, and extension/retraction of the compactor.

[0045] In one example, the controller is programmed to cause the outlet to translate away from the compactor and to extend the cutting module during a severing event.

[0046] In one example, the controller is programmed to cause the outlet to translate toward the compactor and to retract the cutting module during an anchoring event.

[0047] In one example, the print head further includes a cutting module located between the outlet and the compactor.

[0048] In one example, the cutting module is configured to translate relative to the both the outlet and the compactor.

[0049] In another example, the present disclosure is directed to another method of additively manufacturing a composite structure. This method may include discharging a material through an outlet along a central axis of the outlet, and compacting the material at a location downstream of the outlet relative to a trajectory of the discharging material. The method may also include selectively translating the outlet along the trajectory relative to the location.

[0050] In one example, the method further includes clamping the material at a clamping location upstream of the outlet, wherein selectively translating the outlet includes translating the outlet together with the clamping location.

[0051] In another example, the present disclosure is directed to another additive manufacturing system. This system may include a support, and a print head operatively connected to and moveable by the support. The print head may include an outlet configured to discharge a material in a trajectory along a central axis of the outlet, and a compactor disposed downstream of the outlet relative to the trajectory and configured to press the material transversely against an adjacent surface. The system may also include a cutting module located between the outlet and the compactor. The compactor and the cutting module may be configured to move together relative to the outlet.

[0052] In one example, a movement direction of the compactor and the cutting module is towards and away from the material discharging from the outlet.

[0053] In one example, the cutting module is configured to additionally move relative to the compactor.

[0054] In one example, the system further includes a controller programmed to cause the cutting module and the compactor to move.

[0055] In one example, the controller is programmed to cause the cutting module and the compactor to move together during a starting event when the cutting module is retracted.

[0056] In one example, the controller is programmed to cause the cutting module to extend relative to the compactor during a severing event.

[0057] In one example, the print head further includes a first actuator connecting the compactor and the cutting module to a remainder of the print head.

[0058] In one example, the print head further includes a second actuator connecting the cutting module to the first actuator.

[0059] In one example, the cutting module includes a blade and a third actuator configured to rotate the blade.

[0060] In one example, the print head further includes a counterbalance connecting the compactor and the cutting module to a remainder of the print head.

[0061] In one example, the cutting module includes a rotary blade having a polygonal shape with a plurality of vertexes.

[0062] In one example, the print head further includes a first rail, and at least a first carriage configured to slide along the first rail, the at least a first carriage being operatively connected to the compactor and the cutting module.

[0063] In one example, the print head further includes a second rail operatively connected to the first rail, and at least a second carriage configured to slide along the second rail, the at least a second carriable being operatively connected to the cutting module.

[0064] In one example, the print head further includes a spring connecting the compactor to the first carriage.

[0065] In one example, the compactor forms a portion of a compacting/curing module that is further configured to expose the material to a cure energy.

[0066] In one example, the compacting/curing module includes a first source configured to direct the cure energy through the compactor.

[0067] In one example, the compacting/curing module further includes a second source configured to direct the cure energy to a location trailing the compactor.

[0068] In one example, the first source is tilted to direct the cure energy rearward through the compactor toward the location trailing the compactor and includes a first pair of light pipes at opposing ends of the compactor that are tilted to direct the cure energy inwards towards each other. The second source may be tilted to direct the cure energy forward toward the compactor

and includes a second pair of spaced-apart light pipes that are tilted to direct the cure energy inwards towards each other.

[0069] In another example, the present disclosure is directed to another method of additively manufacturing a composite structure. This method may include discharging a material through an outlet along a central axis of the outlet, and compacting the material with a compactor at a location downstream of the outlet relative to a trajectory of the discharging material. The method may also include cutting the material with a cutting module at a mid-location between the outlet and the compactor, and selectively translating the compactor and the cutting module together relative to the outlet.

[0070] In another example, the method further includes selectively translating the cutting module relative to the compactor.

Brief Description of the Drawings

[0071] Fig. 1 is a diagrammatic illustration of an exemplary disclosed additive manufacturing system;

[0072] Figs. 2 and 3 are diagrammatic illustrations of an exemplary disclosed print head that may form a portion of the additive manufacturing system of Fig. 1;

[0073] Fig. 4 is a cross-sectional illustration of an exemplary disclosed reinforcement supply portion of the print head of Figs. 2 and 3;

[0074] Figs. 5-8 are diagrammatic illustrations of exemplary disclosed guide portions of the print head of Figs. 2 and 3;

[0075] Fig. 9 is a cross-sectional illustration of an exemplary disclosed debris collecting portion of the print head of Figs. 2 and 3;

[0076] Figs. 10 and 11 are diagrammatic and cross-sectional illustrations, respectively, of an exemplary disclosed tensioning portion of the print head of Figs. 2 and 3;

[0077] Figs. 12 and 13 are diagrammatic and cross-sectional illustrations, respectively, of an exemplary disclosed matrix supply portion of the print head of Figs. 2 and 3;

[0078] Figs. 14 and 15 are diagrammatic illustrations and Fig. 16 is a cross-sectional illustration of an exemplary disclosed clamping portion of the print head of Figs. 2 and 3;

[0079] Figs. 17 and 18 are diagrammatic and cross-sectional illustrations, respectively, of an exemplary disclosed wetting portion of the print head of Figs. 2 and 3;

Claims

What is claimed is:

1. An additive manufacturing system, comprising:

a support;

a print head operatively connected to and moveable by the support, the print head including:

a supply of continuous reinforcement;

an outlet configured to discharge the continuous reinforcement; and

a tensioning module disposed between the supply and outlet, the tensioning module being configured to generate a signal indicative of at least one of a tension in the continuous reinforcement and a position of the tensioning module; and comprising:

a swing arm;

first and second redirects located at first and second ends of the swing arm and configured to receive the continuous reinforcement, the first redirect being located upstream of the second redirect relative to travel of the continuous reinforcement through the print head;

a pivot coincident with the first redirect; and

a rotary sensor configured to generate the signal during pivoting of the swing arm about the pivot;

and the system further including a processor programmed to selectively cause the supply to dispense the continuous reinforcement based on the signal.

2. The additive manufacturing system of claim 1, further including a wetting module configured to wet the continuous reinforcement with a matrix prior to discharge from the outlet, wherein the tensioning module is located between the supply and the wetting module.

3. The additive manufacturing system of claim 1, wherein the tensioning module is configured such that the continuous reinforcement is passed around the first and second redirects.

4. The additive manufacturing system of claim 1, wherein the at least one redirect is rotationally mounted to the end of the swing arm.

5. The additive manufacturing system of claim 1, wherein the processor is configured to selectively cause the supply to vary a level of tension in the continuous reinforcement, based on an application of the system.

6. The additive manufacturing system of claim 5, wherein the level of tension may be adjusted based on threshold adjustments associated with when an actuator is turned on/off and/or what speeds and/or torques are applied by the actuator in response to the signal.

7. The additive manufacturing system of claim 1, wherein the rotary sensor is associated with the first redirect.

8. The additive manufacturing system of claim 1, further including a counterbalance mounted to the swing arm at the first end.

9. The additive manufacturing system of claim 8, further including a spring at the first end and configured to bias the swing arm toward a low-tension position.

10. The additive manufacturing system of claim 1, further including a hard end stop located at a first side of the swing arm and configured to limit a low-tension position of the swing arm.

11. The additive manufacturing system of claim 10, further including a biased end stop located at a second side of the swing arm and configured to limit a high-tension position of the swing arm.

12. The additive manufacturing system of claim 1, further including a biased end stop located at a first side of the swing arm and configured to limit a high-tension position of the swing arm.

13. A method of controlling tension in a continuous reinforcement of an additive manufacturing system, the system comprising:

a support;

a print head operatively connected to and moveable by the support, the print head including:

a supply of continuous reinforcement;

an outlet configured to discharge the continuous reinforcement; and

a tensioning module disposed between the supply and outlet, the tensioning module being configured to generate a signal indicative of at least one of a tension in the continuous reinforcement and a position of the tensioning module, and comprising:

a swing arm;

first and second redirects located at first and second ends of the swing arm and configured to receive the continuous reinforcement, the first redirect being located upstream of the second redirect relative to travel of the continuous reinforcement through the print head;

a pivot coincident with the first redirect; and

a rotary sensor configured to generate the signal during pivoting of the swing arm about the pivot;

and the method comprising:

receiving, by a processor, the signal; and

selectively causing, by the processor, the supply to dispense the continuous reinforcement based on the signal.

14. A computer program product comprising computer program code configured, when executed on a computer processor, to undertake a method in relation to an additive manufacturing system, the system comprising:

a support;

a print head operatively connected to and moveable by the support, the print head including:

a supply of continuous reinforcement;

an outlet configured to discharge the continuous reinforcement; and

a tensioning module disposed between the supply and outlet, the tensioning module being configured to generate a signal indicative of at least one of a tension in the continuous reinforcement and a position of the tensioning module, and comprising:

a swing arm;

first and second redirects located at first and second ends of the swing arm and configured to receive the continuous reinforcement, the first redirect being located upstream of the second redirect relative to travel of the continuous reinforcement through the print head;

a pivot coincident with the first redirect; and

a rotary sensor configured to generate the signal during pivoting of the swing arm about the pivot;

and the method comprising:

receiving, by a processor, the signal; and

selectively causing, by the processor, the supply to dispense the continuous reinforcement based on the signal.