Although various embodiments of apparatus and methods for automating the fiber laying process during the repair of composite structures will be described in some detail below, one or more of those embodiments may be characterized by one or more of the following aspects.

One aspect of the subject matter disclosed in detail below is an automated method for adding composite material to a composite structure under computer control, comprising ~~continuously laying down successive portions of a continuous fiber roving on the composite structure while wetting each successive portion with epoxy–hardener mixture in a liquid state. This method may further comprise: cutting the dry fiber roving to establish a length of fiber roving to be laid; and allowing the epoxy–hardener mixture on the length of fiber roving to cure in place on the composite structure at ambient temperature. The dry fiber roving is a continuous bundle of unidirectional (i.e., generally parallel, non-twisted and non-entangled) reinforcement fibers (e.g., carbon fibers). The method further comprises: mixing liquid epoxy and liquid hardener in a mixer to form the epoxy–hardener mixture; feeding epoxy–hardener mixture from the mixer to a printing roller; and transferring epoxy–hardener mixture from the printing roller to the dry fiber roving.~~mixing liquid epoxy and liquid hardener in a mixer to form the epoxy-hardener mixture; feeding epoxy-hardener mixture from the mixer to a printing roller; absorbing epoxy-hardener mixture in a mixture-absorbing layer of the printing roller; wetting successive portions of a continuous fiber roving by desorbing epoxy-hardener mixture from the mixture-absorbing layer of the printing roller; passing each successive portion of the continuous fiber roving through a nip formed by the printing roller and the composite structure with desorbed epoxy-hardener mixture applied thereon; and continuously laying down successive wetted portions of the continuous fiber roving on the composite structure with pressure exerted by the printing roller.

~~In accordance with some embodiments, the method described in the preceding paragraph further comprises absorbing epoxy–hardener mixture in a mixture-absorbing layer of the printing roller, wherein each successive portion of the fiber roving passes through a nip formed by the printing roller and the composite structure with epoxy–hardener mixture that has desorbed from the mixture-absorbing layer of the printing roller.~~

Another aspect of the subject matter disclosed in detail below is an automated method for adding composite material to a composite structure, comprising: (a) placing a printing roller adjacent to a first area of the composite structure to form a nip therebetween; (b) transferring an epoxy–hardener mixture in a liquid state onto the printing roller; (c) rotating the printing roller; (d) feeding a dry fiber roving through the nip; (e) transferring epoxy–hardener mixture from

the printing roller to a portion of the dry fiber roving that is passing through the nip; and (f) pressing the portion of the fiber roving with transferred epoxy–hardener mixture on the composite structure, wherein steps (d) through (f) are performed while the printing roller is rotating under computer control. In accordance with one proposed implementation, step (b) comprises absorbing epoxy–hardener mixture in a mixture-absorbing layer of the printing roller and step (e) comprises wetting the portion of the fiber roving that is passing through the nip with epoxy–hardener mixture that has desorbed from the mixture-absorbing layer of the printing roller. The method may further comprise attaching the mixture-absorbing layer of the printing roller around a periphery of a roller core (made of non-mixture-absorbing material) of the printing roller.

A further aspect of the subject matter disclosed in detail below is an apparatus for adding composite material to a composite structure, comprising: a mixer for mixing liquid ingredients contained therein; tubing having one end in fluid communication with the mixer for receiving a liquid mixture from the mixer; a dry fiber roll having a dry fiber roving wound thereon; a printer head comprising a printing roller, a fiber guide configured to guide successive portions of dry fiber roving paid out from the dry fiber roll toward the printing roller, and a fitting in fluid communication with another end of the tubing for receiving liquid mixture therefrom and having an opening adjacent to the printing roller that enables liquid mixture to flow onto the printing roller.

In accordance with some embodiments of the apparatus described in the preceding paragraph, the printing roller comprises a roller core having a periphery and a mixture-absorbing layer attached to the periphery of the roller core. In accordance with one proposed implementation, the mixture-absorbing layer of the printing roller is made of a bleeder material, such as fiberglass or polyester woven fabric.

CLAIMS

~~1. A method for adding composite material to a composite structure, comprising continuously laying down successive portions of a continuous fiber roving on the composite structure while wetting successive portions with an epoxy–hardener mixture.~~

~~2. The method as recited in claim 1, further comprising:~~

~~cutting the fiber roving to establish a length of fiber roving to be laid; and~~

~~allowing the epoxy–hardener mixture on the length of fiber roving to cure in place on the composite structure at ambient temperature.~~

~~3. The method as recited in any of claims 1-2, wherein the fiber roving is a continuous bundle of unidirectional reinforcement fibers, the method further comprising paying out the fiber roving from a roll.~~

~~4. The method as recited in any of claims 1-3, further comprising:~~

~~mixing liquid epoxy and liquid hardener in a mixer to form the epoxy–hardener mixture;~~

~~feeding epoxy–hardener mixture from the mixer to a printing roller; and~~

~~transferring epoxy–hardener mixture from the printing roller to the fiber roving.~~

~~5. The method as recited in claim 4, further comprises absorbing epoxy–hardener mixture in a mixture-absorbing layer of the printing roller, wherein each successive portion of the fiber roving passes through a nip formed by the printing roller and the composite structure with epoxy–hardener mixture that has desorbed from the mixture-absorbing layer of the printing roller.~~

6. The method as recited in any of claims 1-5, further comprising removing material from an area of the composite structure that includes a non-conformity until the non-conformity is removed and a cavity is formed, wherein the wetted successive portions of fiber roving are laid inside the cavity.

7. A method for adding composite material to a composite structure, comprising:

(a) placing a printing roller adjacent to a first area of the composite structure to form a nip therebetween;

(b) transferring an epoxy–hardener mixture in a liquid state onto the printing roller;

(c) rotating the printing roller;

(d) feeding a fiber roving through the nip;

(e) transferring the epoxy–hardener mixture from the printing roller to a portion of the fiber roving that is passing through the nip; and

(f) pressing the portion of the fiber roving with the transferred epoxy–hardener mixture on the composite structure,

wherein steps (d) through (f) are performed while the printing roller is rotating.

8. The method as recited in claim 7, wherein step (b) comprises absorbing epoxy–hardener mixture in a mixture-absorbing layer of the printing roller and step (e) comprises wetting the portion of the fiber roving that is passing through the nip with epoxy–hardener mixture that has desorbed from the mixture-absorbing layer of the printing roller.

9. The method as recited in claim 8, further comprising attaching the mixture-absorbing layer of the printing roller around a periphery of a roller core of the printing roller.

~~10. The method as recited in any of claims 7-9, wherein at least steps (c) through (f) are continuously performed until a first length of fiber roving with transferred epoxy-hardener mixture has been pressed on the composite structure.~~

~~11. The method as recited in claim 10, further comprising cutting the fiber roving at a position upstream from the nip to produce the first length of fiber roving.~~

~~12. The method as recited in claim 11, further comprising:~~

~~placing the printing roller adjacent to a second area of the composite structure with a nip therebetween;~~

~~repeating steps (b) through (f), wherein at least steps (d) through (f) are continuously performed until a second length of fiber roving with transferred epoxy-hardener mixture has been pressed on the composite structure; and~~

~~cutting the fiber roving at a position upstream from the nip to produce the second length of fiber roving.~~

~~13. The method as recited in claim 12, wherein the first and second lengths of fiber roving are adjacent to each other on the composite structure.~~

~~14. The method as recited in claim 13, further comprising allowing the epoxy-hardener mixture on the first and second lengths of the fiber roving to cure at ambient temperature.~~

~~15. The method as recited in any of claims 7-14, wherein the fiber roving is a continuous bundle of unidirectional reinforcement fibers, the method further comprising paying out the fiber roving from a roll.~~

~~16. The method as recited in any of claims 7-15, further comprising mixing liquid epoxy and liquid hardener in a mixer to form the~~

epoxy–hardener mixture, wherein step (c) comprises feeding epoxy–hardener mixture from the mixer to the printing roller.

17. An apparatus for adding composite material to a composite structure, comprising:

a mixer for mixing liquid ingredients contained therein;

tubing having one end in fluid communication with the mixer for receiving a liquid mixture from the mixer;

a fiber roll having a fiber roving wound thereon;

a printer head comprising a printing roller, a fiber guide configured to guide successive portions of fiber roving from the fiber roll toward the printing roller, and a fitting in fluid communication with another end of the tubing for receiving liquid mixture therefrom and having an opening adjacent to the printing roller that enables liquid mixture to flow onto the printing roller.

18. The apparatus as recited in claim 17, wherein the printing roller comprises a roller core having a periphery and a mixture-absorbing layer attached to the periphery of the roller core.

19. The apparatus as recited in claim 18, wherein the mixture-absorbing layer of the printing roller is made of bleeder material.

20. The apparatus as recited in any of claims 17-19, wherein the printer head further comprises:

front and back plates fixedly coupled to each other;

an axle having opposite ends affixed to the front and back plates respectively, the printing roller being rotatably coupled to the axle; and

a compliant linear guide comprising a base fixedly coupled to the front and back plates, a pair of support arms to which the axle is fixedly coupled, the pair of support arms being slidably translatable relative to the base,

~~and a compression spring that exerts a spring force on the printing roller in a direction parallel to the front plate,~~

~~wherein a portion of the printing roller projects beyond respective edges of the front and back plates, and the fiber guide is disposed between and fixedly coupled to the front and back plates.~~

~~21. The apparatus as recited in claim 20, wherein the printer head further comprises: first and second pairs of fiber feeding rollers; a first motor mechanically coupled to one fiber feeding roller of the first pair of fiber feeding rollers; a second motor mechanically coupled to one fiber feeding roller of the second pair of fiber feeding rollers; and a cutter disposed between the first and second pairs of fiber feeding rollers.~~

1. An automated method for adding composite material to a composite structure under computer control, comprising:

mixing liquid epoxy and liquid hardener in a mixer to form the epoxy-hardener mixture;

feeding epoxy-hardener mixture from the mixer to a printing roller;

absorbing epoxy-hardener mixture in a mixture-absorbing layer of the printing roller;

wetting successive portions of a continuous fiber roving by desorbing epoxy-hardener mixture from the mixture-absorbing layer of the printing roller;

passing each successive portion of the continuous fiber roving through a nip formed by the printing roller and the composite structure with desorbed epoxy-hardener mixture applied thereon; and

continuously laying down successive wetted portions of the continuous fiber roving on the composite structure with pressure exerted by the printing roller.

2. The method as recited in claim 1, further comprising:

cutting the fiber roving to establish a length of fiber roving to be laid; and

allowing the epoxy-hardener mixture on the length of fiber roving to cure in place on the composite structure at ambient temperature.

3. The method as recited in claim 1, wherein the fiber roving is a continuous bundle of unidirectional reinforcement fibers, the method further comprising paying out the fiber roving from a roll.

4. The method as recited in claim 1, further comprising removing material from an area of the composite structure that includes a non-conformity until the non-conformity is removed and a cavity is formed, wherein the wetted successive portions of fiber roving are laid inside the cavity.

5. An automated method for adding composite material to a composite structure, comprising:

(a) placing a printing roller adjacent to a first area of the composite structure to form a nip therebetween;

(b) transferring an epoxy-hardener mixture in a liquid state onto the printing roller;

(c) rotating the printing roller;

(d) feeding a fiber roving through the nip;

(e) transferring the epoxy-hardener mixture from the printing roller to a portion of the fiber roving that is passing through the nip; and

(f) pressing the portion of the fiber roving with the transferred epoxy-hardener mixture on the composite structure,

wherein steps (d) through (f) are performed while the printing roller is rotating under computer control, step (b) comprises absorbing epoxy-hardener mixture in a mixture-absorbing layer of the printing roller and step (e) comprises wetting the portion of the fiber roving that is passing through the nip with epoxy-hardener mixture that has desorbed from the mixture-absorbing layer of the printing roller.

6. The method as recited in claim 5, further comprising attaching the mixture-absorbing layer of the printing roller around a periphery of a roller core of the printing roller.

7. The method as recited in claim 5, wherein at least steps (c) through (f) are continuously performed until a first length of fiber roving with transferred epoxy-hardener mixture has been pressed on the composite structure.

8. The method as recited in claim 7, further comprising cutting the fiber roving at a position upstream from the nip to produce the first length of fiber roving.

9. The method as recited in claim 8, further comprising:

placing the printing roller adjacent to a second area of the composite structure with a nip therebetween;

repeating steps (b) through (f), wherein at least steps (d) through (f) are continuously performed until a second length of fiber roving with transferred epoxy-hardener mixture has been pressed on the composite structure; and

cutting the fiber roving at a position upstream from the nip to produce the second length of fiber roving.

10. The method as recited in claim 9, wherein the first and second lengths of fiber roving are adjacent to each other on the composite structure.

11. The method as recited in claim 10, further comprising allowing the epoxy-hardener mixture on the first and second lengths of the fiber roving to cure at ambient temperature.

12. The method as recited in claim 5, wherein the fiber roving is a continuous bundle of unidirectional reinforcement fibers, the method further comprising paying out the fiber roving from a roll.

13. The method as recited in claim 5, further comprising mixing liquid epoxy and liquid hardener in a mixer to form the epoxy-hardener mixture, wherein step (c) comprises feeding epoxy-hardener mixture from the mixer to the printing roller.