part cavity during out-of-autoclave curing, and finally can reduce in size to be removed from the part after cure.

SUMMARY

In an example, a mandrel for a composite part is described that includes an upper-mandrel portion, a lower-mandrel portion, and a mid-mandrel portion between the upper-mandrel portion and the lower-mandrel portion. The mandrel also includes a cavity defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion, and an actuator movable in the cavity between a first position in the cavity and a second position in the cavity. The actuator includes a plurality of segments coupled to each other by a plurality of linkages to allow the actuator to bend. The mandrel further includes an exterior surface defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion. The exterior surface is configured to support the composite part. A perimeter of the exterior surface has a first length when the actuator is in the first position in the cavity and the perimeter has a second length when the actuator is in the second position in the cavity. The first length is greater than the second length such that the mandrel is in an expanded state when the actuator is in the first position and the mandrel is in a contracted state when the actuator is in the second position.

In another example, a method of repairing a part with a mandrel is described that includes configuring a mandrel in a contracted state. The mandrel includes an upper-mandrel portion, a lower-mandrel portion, and a mid-mandrel portion between the upper-mandrel portion and the lower-mandrel portion. The mandrel also includes a cavity defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion. The mandrel further includes an actuator, which is movable in the cavity between a first position in the cavity and a second position in the cavity, and an exterior surface defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion. The actuator includes a plurality of segments coupled to each other by a plurality of linkages to allow the actuator to bend. A perimeter of the exterior surface has a first length when the actuator is in the first position in the cavity and the perimeter has a second length when the actuator is in the second position in the cavity. The first length is greater than the second length such that the mandrel is in an expanded state when the actuator is in the first position and the mandrel is in the contracted state when the actuator is in the second position.

The method of repairing the part also includes inserting the mandrel, in the contracted state, in an interior space of a part. After inserting the mandrel in the interior space of the part, the method includes moving the actuator from the second position to the first position to

expand the mandrel from the contracted state to the expanded state. While the mandrel is in the expanded state, the method includes repairing the part. After repairing the part, the method includes moving the actuator from the first position to the second position to contract the mandrel from the expanded state to the contracted state. After contracting the mandrel, the method includes removing the mandrel from the interior space of the part.

In another example, a method of forming a part with a mandrel is described that includes laying up a plurality of layers on a trough and positioning a mandrel, in an expanded state, on the plurality of layers in the trough. The mandrel includes an upper-mandrel portion, a lower-mandrel portion, and a mid-mandrel portion between the upper-mandrel portion and the lower-mandrel portion. The mandrel also includes a cavity defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion. The mandrel further includes an actuator, which is movable in the cavity between a first position in the cavity and a second position in the cavity, and an exterior surface defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion. The actuator includes a plurality of segments coupled to each other by a plurality of linkages to allow the actuator to bend. A perimeter of the exterior surface has a first length when the actuator is in the first position in the cavity and the perimeter has a second length when the actuator is in the second position in the cavity. The first length is greater than the second length such that the mandrel is in an expanded state when the actuator is in the first position and the mandrel is in the contracted state when the actuator is in the second position.

The method of forming the part also includes positioning a fuselage skin on the plurality of layers to form an interior space between the plurality of layers and the fuselage skin. The mandrel is in the interior space. The method further includes co-curing the plurality of layers and the fuselage skin, and moving the actuator from the first position to the second position to contract the mandrel from the expanded state to the contracted state. After contracting the mandrel, the method includes removing the mandrel from the interior space.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE FIGURES

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode

CLAIMS

What is claimed is:

1. A mandrel for a composite part, comprising:

an upper-mandrel portion;

a lower-mandrel portion;

a mid-mandrel portion between the upper-mandrel portion and the lower-mandrel portion;

a cavity defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion;

an actuator movable in the cavity between a first position in the cavity and a second position in the cavity, wherein the actuator comprises a plurality of segments coupled to each other by a plurality of linkages to allow the actuator to bend; and

an exterior surface defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion, wherein the exterior surface is configured to support the composite part,

wherein a perimeter of the exterior surface has a first length when the actuator is in the first position in the cavity and the perimeter has a second length when the actuator is in the second position in the cavity, and

wherein the first length is greater than the second length such that the mandrel is in an expanded state when the actuator is in the first position and the mandrel is in a contracted state when the actuator is in the second position.

2. The mandrel of claim 1, wherein the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion each have a plurality of kerfs along a longitudinal axis extending from a first end of the mandrel to a second end of the mandrel.

3. The mandrel of claim 2, wherein the plurality of kerfs of the mid-mandrel portion extend from the lower-mandrel portion to the upper-mandrel portion at an angle in a direction from the first end to the second end.

4. The mandrel of any one of claims 1-3, wherein the mid-mandrel portion comprises a first mid-mandrel portion and a second mid-mandrel portion on opposing sides of the cavity.

5. The mandrel of claim 4, wherein the actuator urges the first mid-mandrel portion and the second mid-mandrel portion outwardly away from each other as the actuator moves from the second position to the first position, and

wherein the first mid-mandrel portion and the second mid-mandrel portion urge the upper-mandrel portion upwardly away from the lower-mandrel portion responsive to the actuator urging first mid-mandrel portion and the second mid-mandrel portion outwardly.

6. The mandrel of claim 5, wherein the upper-mandrel portion has a bottom surface that engages a first top surface of the first mid-mandrel portion and a second top surface of the second mid-mandrel portion, and

wherein the first top surface, the second top surface, and the bottom surface each have a sloped profile,

wherein the engagement of the bottom surface with the first top surface and the second top surface urges the upper-mandrel portion upwardly responsive to the actuator urging first mid-mandrel portion and the second mid-mandrel portion outwardly.

7. The mandrel of any one of claims 5-6, wherein the first mid-mandrel portion and the second mid-mandrel portion urge the lower-mandrel portion downwardly away from the upper-mandrel portion responsive to the actuator urging first mid-mandrel portion and the second mid-mandrel portion outwardly.

8. The mandrel of any one of claims 1-7, wherein the cavity comprises a first section and a second section, and

wherein a width of the cavity in the first section is smaller than the width of the cavity in the second section.

9. The mandrel of claim 8, wherein an outer surface of the actuator has a width that is smaller than the width of the cavity in the second section and greater than the width of the cavity in the first section.

10. The mandrel of any one of claims 1-9, further comprising:

a plurality of guide protrusions extending into the cavity from the upper-mandrel portion, the mid-mandrel portion, and the lower-mandrel portion; and

a plurality of guide slots on the actuator,

wherein each of the plurality of guide slots receives a respective one of the plurality of guide protrusions to guide movement of the actuator between the first position and the second position.

11. The mandrel of claim 10, wherein the plurality of guide protrusions and the plurality of guide slots are T-shaped.

12. A method of repairing a part with a mandrel, comprising:

configuring a mandrel in a contracted state, wherein the mandrel comprises:

an upper-mandrel portion,

a lower-mandrel portion,

a mid-mandrel portion between the upper-mandrel portion and the lower-mandrel portion,

a cavity defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion, and

an actuator movable in the cavity between a first position in the cavity and a second position in the cavity, wherein the actuator comprises a plurality of segments coupled to each other by a plurality of linkages to allow the actuator to bend;

an exterior surface defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion,

wherein a perimeter of the exterior surface has a first length when the actuator is in the first position in the cavity and the perimeter has a second length when the actuator is in the second position in the cavity, and

wherein the first length is greater than the second length such that the mandrel is in an expanded state when the actuator is in the first position and the mandrel is in the contracted state when the actuator is in the second position;

inserting the mandrel, in the contracted state, in an interior space of a part;

after inserting the mandrel in the interior space of the part, moving the actuator from the second position to the first position to expand the mandrel from the contracted state to the expanded state;

while the mandrel is in the expanded state, repairing the part;

after repairing the part, moving the actuator from the first position to the second position to contract the mandrel from the expanded state to the contracted state; and

after contracting the mandrel, removing the mandrel from the interior space of the part.

13. The method of claim 12, wherein moving the actuator from the second position to the first position comprises urging the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion outwardly away from each other to expand the mandrel.

14. The method of any one of claims 12-13, wherein inserting the mandrel in the interior space of the part comprises bending the mandrel along an arcing contour of the part,

wherein the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion comprise a plurality of kerfs along a longitudinal axis extending from a first end of the mandrel to a second end of the mandrel to facilitate bending the mandrel.

15. The method of any one of claims 12-14, wherein repairing the part comprises vacuum bagging to cure the part.

16. A method of forming a part with a mandrel, comprising:

laying up a plurality of layers on a trough;

positioning a mandrel, in an expanded state, on the plurality of layers in the trough, wherein the mandrel comprises:

an upper-mandrel portion,

a lower-mandrel portion,

a mid-mandrel portion between the upper-mandrel portion and the lower-mandrel portion,

a cavity defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion,

an actuator movable in the cavity between a first position in the cavity and a second position in the cavity, wherein the actuator comprises a plurality of segments coupled to each other by a plurality of linkages to allow the actuator to bend, and

an exterior surface defined by the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion,

wherein a perimeter of the exterior surface has a first length when the actuator is in the first position in the cavity and the perimeter has a second length when the actuator is in the second position in the cavity, and

wherein the first length is greater than the second length such that the mandrel is in the expanded state when the actuator is in the first position and the mandrel is in a contracted state when the actuator is in the second position;

positioning a fuselage skin on the plurality of layers to form an interior space between the plurality of layers and the fuselage skin, wherein the mandrel is in the interior space;

co-curing the plurality of layers and the fuselage skin;

moving the actuator from the first position to the second position to contract the mandrel from the expanded state to the contracted state; and

after contracting the mandrel, removing the mandrel from the interior space.

17. The method of claim 16, wherein contracting and removing the mandrel are before co-curing the plurality of layers.

18. The method of claim 16, wherein contracting and removing the mandrel are after co-curing the plurality of layers.

19. The method of any one of claims 16-18, wherein the upper-mandrel portion, the lower-mandrel portion, and the mid-mandrel portion each have a plurality of kerfs along a longitudinal axis extending from a first end of the mandrel to a second end of the mandrel, and

wherein positioning the mandrel on the plurality of layers comprises bending the mandrel along a non-linear portion of the plurality of layers.