COMPOSITE LAMINATE DAMAGE DETECTION METHOD USING AN IN-SITU THERMAL GRADIENT AND EXPANSION DIFFERENCES ACROSS THE DAMAGE

FIELD

[0001] The present disclosure relates generally to non-destructive inspection, and more particularly, to systems and methods for non-destructive inspection of composite structures based on thermal expansion differences.

BACKGROUND

[0002] Modern aerospace structures are susceptible to mechanical damage. By way of example, hailstorms or lightning storms can damage an aircraft's skin (e.g., fuselage, wings, or other structures) while the aircraft is in flight or on the ground. Similarly, incidental contact with various ground objects or debris can damage an aircraft's skin. The ability to detect damage to aircraft skins is therefore useful to operators of those aircrafts.

[0003] In aircraft skins, composite materials are increasingly used as substitutes for conventional materials, such as aluminum and steel alloys. The use of composite materials is due in part to the generally high strength-to-weight ratio inherent in composite materials. Composite materials generally include a network of reinforcing fibers that are applied in layers and a resin that substantially wets the reinforcing fibers to form an intimate contact between the resin and the reinforcing fibers.

[0004] For high-energy impacts to an aircraft skin, a delamination, or separation of adjacent layers, can occur under the surface of the aircraft skin. In some examples, delaminations can be larger than any exterior visual indications of potential damage.

SUMMARY

[0005] In one example, a system for in-situ inspection of a composite structure is described. The system includes a surface-strain imaging apparatus, a controller, and an output component. The surface-strain imaging apparatus includes a detector, and is configured to image an area of an outer surface of the composite structure while a temperature of the composite structure warms to thermal equilibrium with a surrounding environment and a temperature gradient exists between an inner surface of the composite structure and the outer surface of the composite structure. The inner surface of the composite structure and the outer surface of the composite structure are separated by multiple internal layers. The controller includes a processor and a memory, and is configured to detect, using data received from the surface-strain imaging apparatus, an out-of-plane displacement of the outer surface in the area caused by the temperature gradient. The controller is

also configured to determine that a height of the out-of-plane displacement of the outer surface exceeds a threshold height, and to flag the area of the outer surface for further inspection based on determining that the height of the out-of-plane displacement exceeds the threshold height. Flagging the area of the outer surface for further inspection includes causing the output component to output a visual indication.

[0006] In another example, a system for in-situ inspection of a composite structure is described. The system includes a surface-strain imaging apparatus, a controller, and an output component. The surface-strain imaging apparatus includes a detector, and is configured to image an area of an outer surface of the composite structure while a temperature of the composite structure warms to thermal equilibrium with a surrounding environment and a temperature gradient exists between an inner surface of the composite structure and the outer surface of the composite structure. The inner surface of the composite structure and the outer surface of the composite structure are separated by multiple internal layers. The controller includes a processor and a memory, and is configured to receive, from the surface-strain imaging apparatus, data indicative of a shape of the outer surface of the composite structure. In addition, the controller is configured to determine whether the data is indicative of a delamination between internal layers of the multiple internal layers of the composite structure. Determining whether the data is indicative of a delamination between internal layers of the composite structure includes determining whether the data is indicative of an out-of-plane displacement having a height that exceeds a threshold height. The output component is configured to provide a visual indication of whether the data is indicative of a delamination between internal layers of the composite structure.

[0007] In another example, a method for in-situ inspection of a composite structure is described. The method includes imaging, using a surface-strain imaging apparatus, an area of an outer surface of the composite structure while a temperature of the composite structure warms to thermal equilibrium with a surrounding environment and a temperature gradient exists between an inner surface of the composite structure and the outer surface of the composite structure. The inner surface of the composite structure and the outer surface of the composite structure are separated by multiple internal layers. The method also includes detecting, by a controller using data received from the surface-strain imaging apparatus, an out-of-plane displacement of the outer surface in the area caused by the temperature gradient. In addition, the method includes determining, by the controller, that a height of the out-of-plane displacement exceeds a threshold height, and flagging, by the controller area of the outer surface for further inspection based on determining that the height of the out-of-plane displacement exceeds the

threshold height. Flagging the area of the outer surface for further inspection includes causing an output component to output a visual indication.

[0008] The features, functions, and advantages that have been discussed can be achieved independently in various examples or may be combined in yet other examples further details of which can be seen with reference to the following description and figures.

BRIEF DESCRIPTION OF THE FIGURES

[0009] The novel features believed characteristic of the illustrative examples are set forth in the appended claims. The illustrative examples, however, as well as a preferred mode of use,

CLAIMS

1. A system for in-situ inspection of a composite structure, the system comprising:

a surface-strain imaging apparatus comprising a detector, the surface-strain imaging apparatus configured to image an area of an outer surface of the composite structure while a temperature of the composite structure warms to thermal equilibrium with a surrounding environment and a temperature gradient exists between an inner surface of the composite structure and the outer surface of the composite structure, wherein the inner surface of the composite structure and the outer surface of the composite structure are separated by multiple internal layers;

a controller comprising a processor and memory, the controller configured to:

detect, using data received from the surface-strain imaging apparatus, an out-of-plane displacement of the outer surface in the area caused by the temperature gradient,

determine that a height of the out-of-plane displacement of the outer surface exceeds a threshold height, and

based on determining that the height of the out-of-plane displacement exceeds the threshold height, flag the area of the outer surface for further inspection; and

an output component,

wherein flagging the area of the outer surface for further inspection comprises causing the output component to output a visual indication.

2. The system of claim 1, wherein flagging the area of the outer surface for further inspection comprises highlighting a region corresponding to the area on a diagram of the composite structure.

3. The system of claim 1 or 2, wherein the composite structure comprises an aircraft skin, and wherein the temperature gradient comprises a temperature difference of at least 20 degrees Celsius between an innermost layer of the aircraft skin and an outermost layer of the aircraft skin.

4. The system of any one of claims 1 to 3, wherein the surface-strain imaging apparatus comprises a shearography system.

5. The system of any one of claims 1 to 3, wherein the surface-strain imaging apparatus further comprises a light source and a retroreflective screen.

6. The system of any one of claims 1 to 3, wherein the surface-strain imaging apparatus comprises a three-dimensional (3D) scanner.

7. The system of any one of claims 1 to 6, wherein the surface-strain imaging apparatus is a handheld measurement instrument.

8. The system of any one of claims 1 to 7, further comprising a robotic crawler, wherein the surface-strain imaging apparatus is attached to the robotic crawler.

9. The system of any one of claims 1 to 7, further comprising an unmanned aerial vehicle (UAV), wherein the surface-strain imaging apparatus is attached to the UAV.

10. The system of any one of claims 1 to 9, wherein:

the surface-strain imaging apparatus is configured to image the area of the outer surface from a first viewpoint, and

the system further comprises another surface-strain imaging apparatus configured to image another area of the outer surface of the composite structure from a second viewpoint that is different from the first viewpoint.

11. A system for in-situ inspection of a composite structure, the system comprising:

a surface-strain imaging apparatus comprising a detector, the surface-strain imaging apparatus configured to image an area of an outer surface of the composite structure while a temperature of the composite structure warms to thermal equilibrium with a surrounding environment and a temperature gradient exists between an inner surface of the composite structure and the outer surface of the composite structure, wherein the inner surface of the composite structure and the outer surface of the composite structure are separated by multiple internal layers;

a controller comprising a processor and memory, the controller configured to:

receive, from the surface-strain imaging apparatus, data indicative of a shape of the outer surface of the composite structure, and

determine whether the data is indicative of a delamination between internal layers of the multiple internal layers of the composite structure, wherein determining whether the data is indicative of a delamination between internal layers of the composite structure comprises determining whether the data is indicative of an out-of-plane displacement having a height that exceeds a threshold height; and

an output component configured to provide a visual indication of whether the data is indicative of a delamination between internal layers of the composite structure.

12. The system of claim 11, wherein the composite structure comprises an aircraft skin, and wherein the temperature gradient comprises a temperature difference of at least 20 degrees Celsius between an innermost layer of the aircraft skin and an outermost layer of the aircraft skin.

13. The system of claim 11 or 12, wherein the surface-strain imaging apparatus is a handheld measurement instrument.

14. The system of any one of claims 11 to 13, wherein:

the surface-strain imaging apparatus is configured to image the area of the outer surface from a first viewpoint, and

the system further comprises another surface-strain imaging apparatus configured to image another area of the outer surface of the composite structure from a second viewpoint that is different from the first viewpoint.

15. A method for in-situ inspection of a composite structure, the method comprising:

imaging, using a surface-strain imaging apparatus, an area of an outer surface of the composite structure while a temperature of the composite structure warms to thermal equilibrium with a surrounding environment and a temperature gradient exists between an inner surface of the composite structure and the outer surface of the composite structure, wherein the inner surface of the composite structure and the outer surface of the composite structure are separated by multiple internal layers;

detecting, by a controller using data received from the surface-strain imaging apparatus, an out-of-plane displacement of the outer surface in the area caused by the temperature gradient;

determining, by the controller, that a height of the out-of-plane displacement exceeds a threshold height; and

based on determining that the height of the out-of-plane displacement exceeds the threshold height, flagging, by the controller, the area of the outer surface for further inspection,

wherein flagging the area of the outer surface for further inspection comprises causing an output component to output a visual indication.

16. The method of claim 15, wherein flagging the area of the outer surface for further inspection comprises highlighting a region corresponding to the area on a diagram of the composite structure.

17. The method of claim 15 or 16, wherein the composite structure comprises an aircraft skin, and wherein the temperature gradient comprises a temperature difference of at least 20 degrees Celsius between an innermost layer of the aircraft skin and an outermost layer of the aircraft skin.

18. The method of any one of claims 15 to 17, wherein the surface-strain imaging apparatus comprises a shearography system.

19. The method of any one of claims 15 to 17, wherein the surface-strain imaging apparatus further comprises a light source and a retroreflective screen.

20. The method of any one of claims 15 to 17, wherein the surface-strain imaging apparatus comprises a three-dimensional (3D) scanner.