Another aspect of the subject matter disclosed in detail below is an ultrasonic imaging system having a B-scanning mode in which time and depth axes ranges and time-gate settings for a B-scan window are based on a correlation of ultrasonic B-scan data with optical cross-section measurement data wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

A further aspect of the subject matter disclosed in detail below is a method for non-destructive inspection of composite structures, comprising: (a) calibrating an ultrasonic inspection system based on correlation of ultrasonic B-scan data and optical cross-section measurement data acquired from reference standards made of composite material, each reference standard having at least one wrinkle; (b) collecting non-destructive inspection data from a part made of composite material using the ultrasonic inspection system after completion of step (a); (c) detecting the presence of a wrinkle in the part based on the non-destructive inspection data collected in step (b); (d) collecting ultrasonic B-scan data from the part using the ultrasonic inspection system; and (e) measuring dimensions of the wrinkle in the part based on the ultrasonic B-scan data collected in step (d), wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards. In accordance with some embodiments, the non-destructive inspection data is collected in step (b) using at least one of the following: an ultrasound technique, infrared thermography, an X-ray backscatter technique, X-ray computed tomography or X-ray laminography.

Yet another aspect of the subject matter disclosed in detail below is a method for non-destructive inspection of composite structures, comprising: (a) calibrating an ultrasonic inspection system based on correlation of ultrasonic B-scan data and optical cross-section measurement data acquired from reference standards made of composite material, each reference standard having at least one wrinkle; (b) collecting ultrasonic B-

scan data from a part made of composite material using the ultrasonic inspection system after completion of step (a); (c) detecting the presence of a wrinkle in the part based on the ultrasonic B-scan data collected in step

(b); and (d) measuring dimensions of the wrinkle in the part based on the ultrasonic B-scan data collected in step (b), wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

A further aspect of the subject matter disclosed in detail below is a method for predicting performance of a wrinkled composite structure, comprising: (a) calibrating an ultrasonic inspection system based on correlation of ultrasonic B-scan data and optical cross-section measurement data acquired from reference standards made of composite material, each reference standard having at least one wrinkle; (b) collecting ultrasonic B-scan data from a wrinkled composite structure using the ultrasonic inspection system after completion of step (a); (c) measuring dimensions of a wrinkle in the wrinkled composite structure based on the ultrasonic B-scan data collected in step (b) to obtain wrinkle feature measurements; (d) generating a structural model of the wrinkled composite structure based on the wrinkle feature measurements obtained in step (c); and (e) performing a structural analysis of the structural model, wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards. This method may further comprise determining whether the part should be rejected or not based on results of the structural analysis.

Other aspects of methods for characterizing wrinkles in composite structures and predicting performance of wrinkled composite structures are disclosed below.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, functions and advantages discussed in the preceding section can be achieved independently in various embodiments or may be combined in yet other embodiments. Various embodiments will be hereinafter described with reference to drawings for the purpose of illustrating the above-described and other aspects.

FIG. 1 is a front view of an ultrasonic inspection system, which includes a flexible transducer array, by which an aircraft structure may be non-destructively inspected.

CLAIMS

1. A method for calibrating an ultrasonic inspection system, comprising:

(a) forming a multiplicity of reference standards made of composite material, each reference standard having at least one wrinkle;

(b) collecting ultrasonic B-scan data from the multiplicity of reference standards using an ultrasonic inspection system;

(c) cutting the reference standards to expose cross sections;

(d) imaging the exposed cross sections to produce optical cross sections;

(e) measuring features of the at least one wrinkle of each reference standard which appear in the optical cross sections to acquire optical cross-section measurement data; and

(f) correlating the ultrasonic B-scan data with the optical cross-section measurement data,

wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

2. The method as recited in claim 1, wherein the optical cross-section measurement data further comprises data representing thicknesses of the respective reference standards.

3. The method as recited in claim 2, wherein step (f) comprises correlating time-of-flight measurements with material depths.

4. The method as recited in claim 3, further comprising selecting time and depth axes ranges and time-gate settings for a B-scan

window based on results of step (f), including the correlating of the time-of-flight measurements with the material depths.

5. An ultrasonic imaging system having a B-scanning mode in which time and depth axes ranges and time-gate settings for a B-scan window are based on a correlation of ultrasonic B-scan data with optical cross-section measurement data,

wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

6. The ultrasonic imaging system as recited in claim 5, wherein the optical cross-section measurement data further comprises data representing thicknesses of the respective reference standards.

7. A method for non-destructive inspection of composite structures, comprising:

(a) calibrating an ultrasonic inspection system based on correlation of ultrasonic B-scan data and optical cross-section measurement data acquired from reference standards made of composite material, each reference standard having at least one wrinkle;

(b) collecting non-destructive inspection data from a part made of composite material using the ultrasonic inspection system after completion of step (a);

(c) detecting the presence of a wrinkle in the part based on the non-destructive inspection data collected in step (b);

(d) collecting ultrasonic B-scan data from the part using the ultrasonic inspection system; and

(e) measuring dimensions of the wrinkle in the part based on the ultrasonic B-scan data collected in step (d),

wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

8. The method as recited in claim 7, wherein the non-destructive inspection data is collected in step (b) using at least one of the following: an ultrasound technique, infrared thermography, or an X-ray backscatter technique.

9. The method as recited in claim 7 or 8, further comprising generating a structural model of the part and performing a structural analysis of the structural model.

10. The method as recited in claim 9, further comprising determining whether the part should be rejected or not based on results of the structural analysis.

11. The method as recited in claim 9 or 10, wherein the structural model is a finite element model and the structural analysis is a finite element model analysis.

12. A method for non-destructive inspection of composite structures, comprising:

(a) calibrating an ultrasonic inspection system based on correlation of ultrasonic B-scan data and optical cross-section measurement data acquired from reference standards made of composite material, each reference standard having at least one wrinkle;

(b) collecting ultrasonic B-scan data from a part made of composite material using the ultrasonic inspection system after completion of step (a);

(c) detecting the presence of a wrinkle in the part based on the ultrasonic B-scan data collected in step (b); and

(d) measuring dimensions of the wrinkle in the part based on the ultrasonic B-scan data collected in step (b),

wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

13. The method as recited in claim 12, further comprising generating a structural model of the part and performing a structural analysis of the structural model.

14. The method as recited in claim 13, further comprising determining whether the part should be rejected or not based on results of the structural analysis.

15. The method as recited in claim 13 or 14, wherein the structural model is a finite element model and the structural analysis is a finite element model analysis.

16. A method for predicting performance of a wrinkled composite structure, comprising:

(a) calibrating an ultrasonic inspection system based on correlation of ultrasonic B-scan data and optical cross-section measurement data acquired from reference standards made of composite material, each reference standard having at least one wrinkle;

(b) collecting ultrasonic B-scan data from a wrinkled composite structure using the ultrasonic inspection system after completion of step (a);

(c) measuring dimensions of a wrinkle in the wrinkled composite structure based on the ultrasonic B-scan data collected in step (b) to obtain wrinkle feature measurements;

(d) generating a structural model of the wrinkled composite structure based on the wrinkle feature measurements obtained in step (c); and

(e) performing a structural analysis of the structural model,

wherein the optical cross-section measurement data comprises data representing wavelengths and maximum depths of wrinkles in respective reference standards.

17. The method as recited in claim 16, further comprising determining whether the wrinkled composite structure should be rejected or not based on results of the structural analysis.

18. The method as recited in claim 16 or 17, wherein the structural model is a finite element model and the structural analysis is a finite element model analysis.