inspected object's surface or sub-surface that at least equals or exceeds the physical determinations made during destructive testing.

SUMMARY

[0004] Aspects of the present aspects, methods, apparatuses and systems are disclosed that relate to the use of small angle X-ray backscattering techniques to non-destructively inspect interlayers for the purpose of confirming with precision the presence or absence of anomalies in the interlayer that could impact optimal bonding when the interlayer is an adhesive layer.

[0005] Aspects of the present methods, systems, and apparatuses create refined imaging at the nano-scale level imaging for, among other things, inspecting composite material adhesive interlayers. When the imaging produced according to presently disclosed techniques does not reveal any anomalies within a composite material adhesive interlayer, the non-destructive inspection confirms that a satisfactory bond has been established, such that the inspected region would pass any mandated bonding strength testing protocols that would otherwise cause the destruction of the inspected material.

[0006] According to one present aspect, a method for non-destructively inspecting a bond line in an adhesive material layer of a composite substrate is disclosed, with the method including positioning a small angle X-ray scattering system proximate to a composite substrate, with the composite substrate including a an adhesive material layer interposed between a composite substrate first side and a composite substrate second side, with the adhesive material layer further including a bond line region. The small angle X-ray scattering system includes first side small angle X-ray scattering system

components positioned on the composite substrate first side, including an X-ray source, a first pinhole aperture and a second pinhole aperture positioned a predetermined distance from the X-ray source; a first vacuum chamber positioned proximate to the pinhole apertures and the composite substrate first side. The X-ray scattering system includes second side small angle X-ray scattering system components positioned on a composite substrate second side, including: a second vacuum chamber positioned proximate to the composite substrate second side, with the second vacuum chamber in communication with an X-ray scintillator; a charged coupled device camera in communication with the scintillator, with the scintillator comprising a scintillating layer. Presently disclosed methods further include activating the small angle X-ray scattering system to emit an X-ray beam from the X-ray source; detecting scattered X-rays on the scintillating layer; and generating imaging signals based on the scattered X-rays impacting the scintillating layer

[0007] According to further aspects, presently disclosed methods further include sending the imaging signals of the scattered X-rays generated on the scintillating layer to a computing device; converting the imaging signals into an image; and displaying the bond line region of the composite component as a bond line region image on a small angle X-ray scattering system output.

[0008] According to another aspect, disclosed methods include detecting the presence or absence of anomalies present in the bond line region.

[0009] Further aspects disclose non-destructively detecting anomalies in a bond line of a composite material, wherein the anomalies detected in the bond line region can comprise a dimension ranging from less than 1 nm to about 1.0 mm or more.

[0009a] According to another aspect, there is provided a system for non-destructively inspecting a composite substrate, said composite substrate comprising a composite substrate first side, a composite substrate second side, and at least one adhesive material layer, said adhesive material layer interposed between the composite substrate first side and the composite substrate second side. The system comprises first side small angle X-ray scattering system components positioned on the composite substrate first side, said first side small angle X-ray scattering system components comprising: a monochromatic X-ray source; a first pinhole aperture and a second pinhole aperture positioned a predetermined distance from the monochromatic X-ray tube; a first vacuum chamber positioned between first pinhole aperture and second pinhole aperture. The system also includes second side small angle X-ray scattering second side system components positioned on the composite substrate second side, said small angle X-ray scattering second side system components comprising: a second vacuum chamber positioned proximate to the composite material second side, said second vacuum chamber in communication with an X-ray scintillator; a charged coupled device in communication with the X-ray scintillator, said scintillator comprising a scintillating layer; imaging software in communication with the charged coupled device; a display in communication with the imaging software. The system is configured to display a microscopic two-dimensional image of the adhesive material layer.

[0010] Further aspects disclose a system for non-destructively inspecting a substrate comprising a composite material, with the system configured to detect nano-scale anomalies in a

substrate bond line, including, for example, a substrate bond line in an epoxy-based composite material substrate, and further including, for example, a bond line in an adhesive layer in a composite substrate. According to a present aspect, the disclosed non-destructive inspection systems are configured to non-destructively inspect substrates, including substrates that include a substrate material having a substrate material first side, a substrate material second side, and at least one interlayer interposed between the substrate material first and second sides. The presently disclosed non-destructive inspection system includes a small angle X-ray scattering system including a microscopic high-resolution nano-focus monochromatic X-ray for non-destructively inspecting a substrate. The system further includes first side system components positioned on a substrate material first side, with the first side system components including: a monochromatic X-ray tube; a first pinhole aperture and a second pinhole aperture positioned a predetermined distance from the X-ray tube; a first vacuum chamber positioned between first pinhole aperture and second pinhole aperture. The system further includes second side system components positioned on a substrate material second side, with the second side system components including a second vacuum chamber positioned proximate to the composite material second side, with the second vacuum chamber in communication with an X-ray scintillator a charged coupled device in communication with the scintillator, and with the X-ray scintillator comprising a scintillating layer. The system further includes imaging software in communication with the charged coupled device, a display in communication with the imaging software, and wherein the system is configured to inspect the substrate material interlayer region.

[0011] According to another aspect, a method for non-destructively inspecting a bond line of an adhesive material layer of a composite substrate is disclosed, with the method including positioning a small angle X-ray scattering apparatus proximate to a composite material substrate,

with the composite material substrate including an adhesive material layer, and with the adhesive material layer including a bond line. The method further includes directing X-rays from the small angle X-ray scattering apparatus to the composite substrate material and detecting scattered X-rays on an X-ray scintillator, generating imaging signals of the scattered X-rays detected on the detector-ray scintillator, generating an image from the imaging signals, and non-destructively determining the integrity of the bond line.

[0012] In a further aspect, the substrate material interlayer region comprises a bond line.

[0013] In another aspect, at least a portion of the substrate material includes a composite material.

[0014] In a further aspect, at least a portion of the substrate material includes a metallic material or a non-metallic material, or combinations thereof.

[0015] In a further aspect, the substrate is a primary structure for an aircraft, with the primary structure including a composite material.

[0016] The features, functions and advantages that have been discussed can be achieved independently in various aspects or may be combined in yet other aspects, further details of which can be seen with reference to the following description and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Having described variations of the disclosure in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein: