Composite Pressure Vessel

Laser Shearography: A powerful solution for Quality Control and NDT inspection of COPV

Composite Overwrapped Pressure Vessels (COPVs)

COPVs are fabricated from fiber based composite materials and epoxy resins that together form the overwrapped structure of a pressure vessel. Continuous fibers used for the overwrapping are usually carbon fiber, glass fiber or Kevlar®. The overwrapped fibers provide the necessary tensile strength properties for the vessel, whilst the epoxy resin carries the required shear loads throughout the composite. The epoxy resin also maintains the fibers' position and alignment. Some COPVs, depending on their type number, will have an inner liner, which acts as a pressure tight fluid retention barrier.

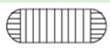
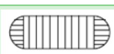
Type	Vessel Body	Inner Liner	Diagram
I	Steel or Aluminum	-	
II	Steel or Aluminum with composite overwrap (Glass or Carbon-fiber composite)	-	
III	Glass or Carbon-fiber composite	Steel or Aluminum	
IV	Glass or Carbon-fiber composite	Polymer (HDPE)	
V	Glass or Carbon-fiber composite	-	

Table 1: COPV Type Comparison[1,2]

Problem: COPV failure modes

The ability to predict and verify specific COPV failure modes is actually a difficult scientific challenge. The failure modes of metallic vessels cannot be applied to COPVs. This is due to a lack of accurate numerical information and models about the various possible failure modes themselves. Practical experiments are still required nowadays in order to determine how to either avoid failure during manufacturing, or detect and control the effects of a damage on the structural life of the pressure vessel.

Shearing of Boss: A Fatigue Mode

Due to the complicated geometry interface between the boss and the pressure vessel, high shear stresses can occur. Consequently, the overwrap over this sensitive zone is also subjected to these shear stresses. Since the overwrap is not designed to face shear, it can easily lead to local damages of the fibers. Fatigue installs itself at these locations and leads to the explosion of the vessel.

Embrittlement of Fibers: A harmful environment consequence

Even though composite materials are well suited to standard environment conditions, COPVs can be exposed to unattended agents and temperature. Consequently, overwrap fibers can become more brittle leading to a non-expected low maximum-hoop-stress. It is extremely important to detect locally broken fibers before the entire structure collapses under the internal pressure.

Impact damage: Broken below the surface

One of the most serious types of failure modes susceptible to COPVs is impact damage. Impact damage is any mechanical damage as a result of interaction between an object and a surface. Impact damage can be potentially catastrophic to the structural integrity and performance of COPVs as it can create Barely Visible Impact Damages (BVIDs). Due to the nature of composites, an impact damaged COPV can face the spreading of fatigue damage (fiber cracking) throughout the overwrap.

[1] Composites Overwrapped Pressure Vessels, A Primer: NASA/SP-2011-573, P.McLaughlan & S.Forth, Johnson Space Center, Houston, Texas, March 2011

[2] The Global Market for CPVs - Drivers, challenges & trends, iCAIM 2014, Leipzig, Germany: June 2014

Failure Mode	Failure Result	Control Phase	Mitigation Method
Shearing of Boss	Catastrophic	Design /NDE	Statistical, NDI
Fatigue Crack Growth in Liner under Composite	Leakage	Design/NDE	Fracture Control (Safe-Life)
Crack Growth in Boss	Catastrophic	Design/NDE	Fracture Control (Safe-Life)
Over Pressurization	Catastrophic	System Design/Operations	Thermal Control and System Design
Stress-Rupture	Catastrophic	Design/Operations	Stress-Rupture Data
Corrosion/Stress-Corrosion of Liner under Composite	Catastrophic	Design/Manufacturing/ Operations	Control of Chemical Environment
Liner under Composite Corrosion/Stress-Corrosion of Boss	Catastrophic	Design/Manufacturing/ Operations	Control of Chemical Environment
Embrittlement of Liner	Catastrophic	Manufacturing/Operations	Metallurgical Control, Control of Thermal and Chemical Environments
Corrosion of Matrix Resin or Fiber	Catastrophic	Manufacturing/Operations	Control of Chemical Environment
Embrittlement of Matrix Resin or Fiber	Catastrophic	Manufacturing/Operations	Control of Cure, Control of Thermal and Chemical Environments
Liner Buckling under Composite/fatigue	Leakage	Manufacturing/NDE	Adhesive Bonding Process Control, Bond-Line NDE
Impact/Mechanical Damage	Catastrophic	Manufacturing/NDE/ Operations	Damage Control
Delamination (of mounting interface and bridging)	Catastrophic	Manufacturing	NDE

Table 2: COPV failure modes[3]

Unlike metallic vessels, composite performance will reduce (substantially) from mechanical impacts. Composites also have a wide range of damage tolerance capacities. For example, carbon fiber is extremely vulnerable to impact damage, compared to Kevlar® and/or glass fiber. Certain vessel designs and overwrap patterns are also more sensitive than others to impacts e.g. exterior helical overwraps are in some designs more damage tolerant than exterior hoop overwraps.
Usually, if a COPV is required to withstand a specific impact energy level to meet a certain damage tolerance criteria, it will be incorporated into the design of the COPV.
In Industry nowadays, if a COPV is damaged, it is directly rejected, regardless of the extent of the damage (structural performance integrity). In order to avoid rejection of still valid COPVs, an inspection technique able to detect and look inside the composite for BVIDs is needed. Not all forms of Impact Damage are catastrophic, however, no method so far could distinguish between them.

Shearography: A powerful solution for COPV quality control and NDT inspection

According to a publication by the UK National Composites Network Best Practice Guide to the Non-Destructive Testing of Composite Materials, Shearography is a key NDT method for detecting; BVIDs (impact damage), delaminations and trans laminar cracking (fatigue cracking) for polymer matrix composites, see table 3.
It has also been used to look at shearing of the boss for COPVs (see Shearing of Boss Application Example on page 6). Shearography can be used not only as an NDI technique, but also as a developmental quality assurance process technique for COPV design.

[3] 2011 NASA Composite Overwrapped Pressure Vessels, A Primer; March 2011 (Courtesy of Lorie Grimes-Ledesma, Ph.D, NASA Jet Propulsion Laboratory, Pasadena, Calif.)

Flaw sought	Visual	Through Trans-mission	Shearo-graphy	Velocity	Low Frequ-ency	Radio-graphy	Acoustic Emission	Thermo-graphy
Fibre type				•				
Porosity	•	✓		•				
Fibre-matrix bond	•						•	
Matrix properties				•				
Fibre misalignment		•			•	•		
Volume fraction		•		•	•	•		
Stacking sequence								
Ply-end discontinuity								
Foreign inclusions		•	•			✓		✓
Trans-laminar cracks		•	✓			•	✓	•
Fibre breakage							✓	
Delamination	✓	✓	✓		✓	•	✓	✓
Moisture ingress				•				
Impact damage	✓		✓					✓

Table 3: NDT comparison chart for flaws sought for polymer matrix composites[4]

Shearography Measurement Principle

Shearography is an optical, NDT technique that provides fast and accurate indications about internal material discontinuities or anomalies in non homogenous materials. Using laser light, a shearing interferometer is able to detect extremely small (sub micro-meter) changes in surface out-of-plane deformation. When a test object is subjected to an appropriate load, a proportional strain is induced on the test surface. If underlying discontinuities are present, the surface will deform unevenly at these locations. This is then interpreted through the shearing inter-ferometer as a change in the phase of the laser light.

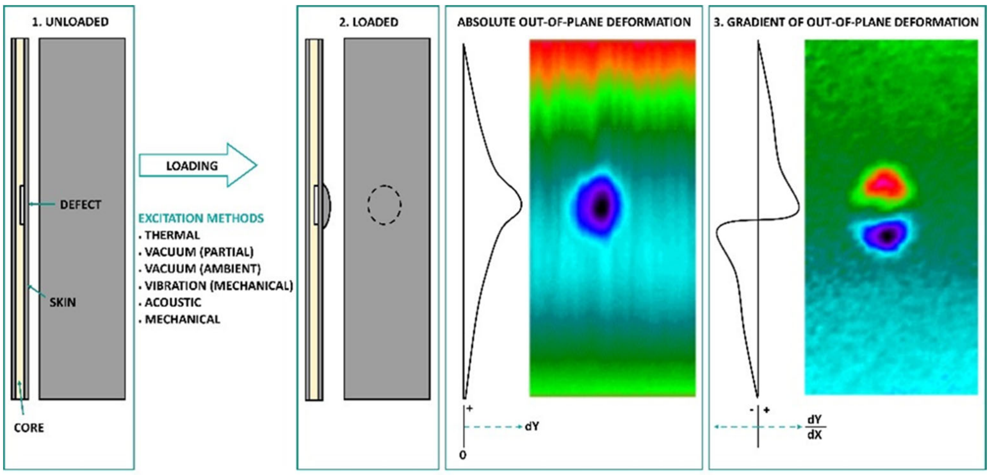


Table 4: Shearography measurement principle

[4] UK National Composites Network publication/Best Practice Guide to the Non-Destructive Testing of Composite Materials by Ajay Kapadia

Application Example COPV: BVIDs in fiberglass

Mechanical impact tests on a Type IV vessel – unidirectional wrapping

Application

A mechanical impact test for bearly invisible impact damage (BVID) in fiberglass COPV (type IV) with unidirectional wrapping.

Setup

The setup consisted of a Q-800 Shearography sensor with two automatic heat lamps rated at 750W each. The lamps were placed at 50 cm from the pressure vessel and switched on for 10 sec.

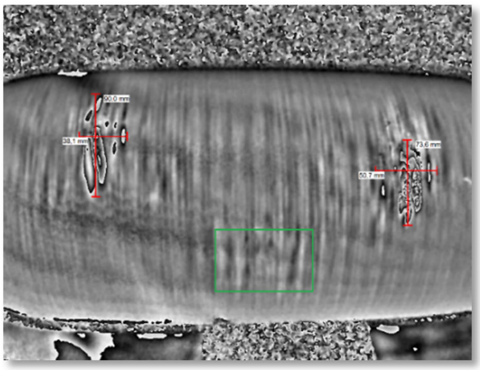


Image 1

Results

Two impacts leading to BVIDs (Bearly Visible Impact Damages). One impact was considered within the acceptable tolerance criteria. If this detection was the only impact, then this COPV tank would have been considered reuseable. Image 1 shows the defect areas detected by Shearography and the corresponding areas located on the live image on the COPV (Image 2).

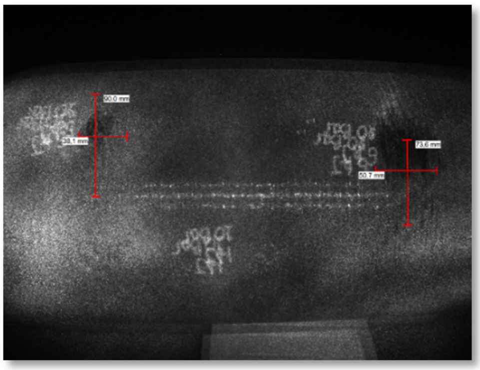


Image 2

Application Example COPV: BVIDs in fiberglass

Mechanical impact tests on a Type IV vessel – multidirectional wrapping

Application

A mechanical impact test for bearly invisible impact damage (BVID) in fiberglass COPV (type IV) with multidirectional wrapping.

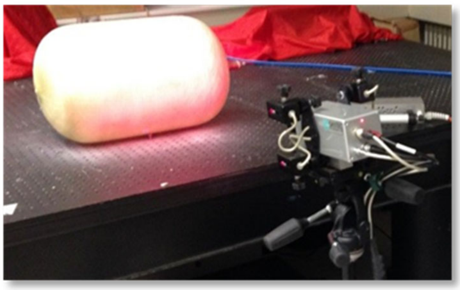


Image 3

Setup

The setup consisted of a Q-800 Shearography sensor. COPV was excited by internal pressurization. Image 3 shows the laboratory set-up of the measurement.

Results

Five impacts were detected. All impacts were considered catastrophic. Image 4 shows the measurement view of the defects with sized dimensions.

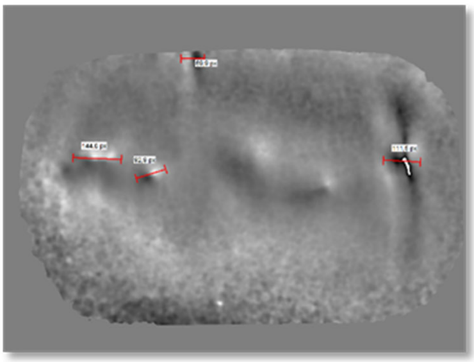


Image 4

Application Example COPV: BVIDs in Carbon fiber

Mechanical impact tests on a Type IV vessel

Application

A mechanical impact test for bearly invisible impact damage (BVID) in fiberglass COPV (type IV) with multidirectional wrapping.

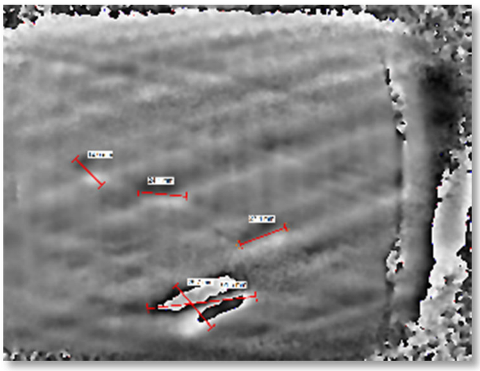
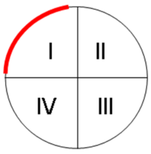


Image 6

Setup

COPV vessel was inspected in sectors using Shearography. Setup consisted of a Q-800 Shearography sensor. COPV was excited by internal pressurization. Image 5 shows laboratory set-up of the measurement and COPV sector definition.

Image 5



COPV Sectors

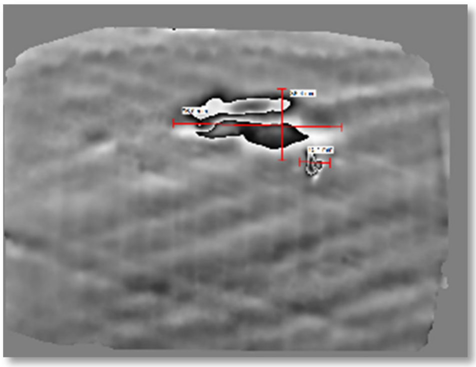


Image 7

Results

Sector 1 had one large and three small defects. Image 6 shows measurement view of the defects with sized dimensions. Sector 2 had one large and one small defect. Image 7 shows measurement view of the defects with sized dimensions.

Application Example Fiber Cracking in Glass fiber

Detecting cracks of composite fibres wrapping on a Type II COPV

Application

Detecting cracks of composite fibers wrapping on a Type II COPV in glass fiber hull around a steel tank.

Image 8

Setup

The setup consisted of a Q-800 Shearography sensor. The COPV was excited by internal low pressurization. Shear settings were set to 10mm at 90°. Image 8 shows laboratory set-up of the measurement.

Results

Two inclusions and one continuous fibers cracking were detected, see image 9. These fibers cracking will definitely lead to the destruction of the pressure vessel if it is pressurized again to its nominal value.

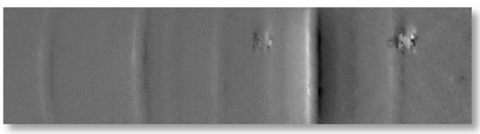


Image 9

Application Example Shearing of Boss

Detecting defects at the boss on a Type IV COPV

Application

Detecting defects due to the shearing at the boss on a Type IV COPV.

Setup

The setup consisted of a Q-800 Shearography sensor and two automatic heat lamps rated at 750W each. The heat lamps were placed 50 cm from the pressure vessel and switched on for 10 seconds. Shear settings were set to 10 mm at 45°.

Results

Three defects were detected around the boss of the COPV indicating that the metallic boss was not well fitted and as such had sheared. Image 10 shows radome sensor live image. Image 11 shows defects around the boss.

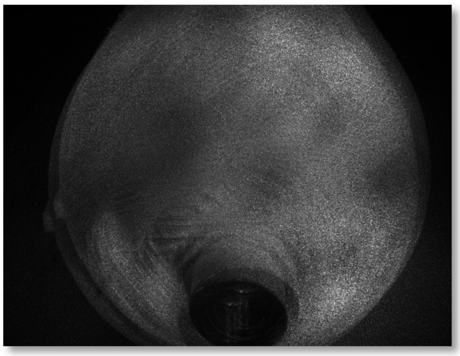


Image 10

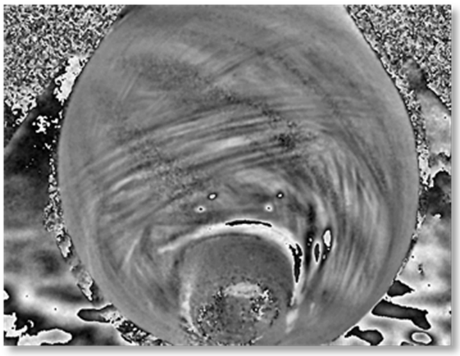


Image 11

Benefits of Dantec Dynamics' Shearography Solution

- Very well suited NDT method for detecting COPV defects in inspection and quality control.
- Certified NDT technique according to standards AIA NAS 410, CEN EN 4179 and ASNT SNT-TC-1A.
- Standard NDT practice for Shearography of polymer matrix composites according to ASTM E2581.
- Can measure, record and interpret data over large areas (~m^2) with very short inspection times (~15 seconds).
- Real-time measurement solution, providing same time inspection results.
- Non-contact optical technique, means specimen under test is not polluted and measurement of non-planar surfaces is easily possible.
- Compact measurement system suitable for flexible in-field or laboratory use.
- Easy and safe usage with 3R classified laser iodes.

Image 12 The Q-800 Portable Shearography system

Q-800 Portable Shearography System

The Q-800 Portable Shearography System is a non-contact, optical NDT measurement solution used for quality control and material inspection of advanced (non homogenous) materials.

Shearography is an optimum NDT solution, tailored specifically for integrated quality control processes, as used in the Aerospace, Automotive, Wind Power, Marine, Aviation, Textile and other Composite related industries. The Q-800 actively supports the entire product life cycle from R&D, to componentry (manufacturing), assembly, end-test and in-service operation.

Applicable materials include, but are not limited to; composite honeycomb, rubber, composite overwrapped pressure vessels (COPV), ceramics, glass-fiber laminates, metal honeycombs, carbon-fiber (CFRP) laminates, fiber-metal laminates, bi-metals, foam-cores, cork, leather and metal-metal bonds.

Depending on the material strength and depth of defects within a sample, Laser Shearography can detect most defects and discontinuities that occur in composite structures, including: disbonds, delaminations, cracked cores, crushed cores, kissing bonds, wrinkling, fluid ingresses, porosity, cracks, repair defects and impact damage (BVIDs). Additional structural information such as ply drops, bulkheads, overlaps, splices, stringers and ribs, can also be detected.

DANTEC DYNAMICS Turn Measurements into Knowledge

Application Note_361_v1
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