LINCOLN COMPOSITES
Fuel Tank Manufacturing, Testing, Field Performance, and Certification

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Component and System Qualification Workshop

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Over 45 years experience
Over 80 configurations
Liner types: aluminum, Inconel, titanium, carbon steel, stainless steel, rubber, plastic
Fiber types: glass, aramid, carbon
Type 2, Type 3, and Type 4 construction
Over 180,000 pressure vessels in service
Volumes from 65 cc to 8500 L
Operating pressures from 35 bar to 1725 bar
Burst pressures up to 3450 bar
Beginnings
- Development initiated in 1990
- 1st Type 4 Tank Certified to ANSI/AGA NGV2

Certifications
- NGV2
- FMVSS 304
- CSA B-51
- ISO 11439
- KHK
- ECE R110
- TUV

Parameters
- CNG Operating Pressures of 207 & 248 bar
- CH2 Operating Pressures from 250 to 950 bar

Proven History
- 17 Years of Service History
- Approximately 100,000 tanks in service
TUFFSHELL™ Tank Details

HDPE Liner

Aluminum Boss

Hybrid Composite

TUFFSHELL®

Reference US patents 5,429,845 & 5,476,189; and International Patents
Manufacturing Process

- Manufacture liner components
- Assemble liner
- Wind composite
- Cure composite
- Proof test
- Leak test
- Final inspection
Tanks for cars
Tank Packs for Trucks
Tank Packs for Buses
High Pressure Gas Transport

- Weight savings of 70–80% compared to steel cylinders
- Higher operating pressure is possible with Type 4 tank
- Improved corrosion resistance, gas compatibility, cyclic fatigue
LINCOLN COMPOSITES has developed the TITAN™ Tank for gas bulk hauling
- Diameter is 1.1 meters
- Length is 11.6 meters
- Operating Pressure is 250 bar
- Water Volume of 8500 liters

Qualification completed and ABS Certification received in 4th Quarter 2009

Approved modules are in the field
- CNG and H2
- Supported by US DOE
- 600 kg H2 at 250 bar
- 800 kg H2 at 350 bar
Stationary Cascades
Qualification Testing

Strength and Life Cycle
- Burst
- Ambient cycling
- Leak before break
- Accelerated stress rupture
- Natural gas/hydrogen cycling
- Boss torque

Environmental
- Environmental fluid exposure
- Extreme temperature cycling
- Bonfire

Damage Tolerance
- Penetration (gunfire)
- Flaw tolerance
- Drop
A Bridge impact was one of the most significant incidents
- Vehicle speed was approximately 75 km/hr (45 mph)
- Tank pressure was about 200 bar (3000 psi)
- Interference was 15 cm (6 inches)
- Vehicle traveled approximately 30 m (100 ft) past bridge
Burst pressure was 597 bar (8660 psi)

- Front tank was most severely damaged
- Requirement is 559 bar (8100 psi) minimum for lot acceptance
- Lot sample burst test was 627 bar (9100 psi)
Field Incidents – Impact and Drop

- Curb hit, visible damage to dome, tank still met burst requirement

- Tank dropped from, dragged by, and run over by heavy duty vehicle, tank still met burst requirement
Field Incidents – Impacts

- Tank impacted by metal shelf support, did not rupture

- Bus hijacked, collided with another heavy vehicle, ran through fence and into parked cars, no reported damage to tanks
Field Incidents – Fire

- Fire in bus engine compartment, hot enough to melt ceramic elements in catalytic converter, PRD activated and all tanks vented safely

- Fire engulfed bus, PRDs activated and all tanks vented safely
Field Incidents – Collision

- Tank mounted in trunk
- Impacted by fully loaded gasoline transport
- No leakage or rupture
- According to the fleet manager, the accident investigator stated that the strength provided by the CNG fuel tank probably saved the driver’s life
Field Ruptures

- Two LC tanks have ruptured in service
  - Rupture in parked passenger vehicle
    - Fire burned inside vehicle for about 20 minutes before tank rupture
    - Vehicle system installation issue
    - PRD was isolated, did not see heat from fire
  - Rupture in delivery vehicle during refueling
    - Tank was not mounted properly
    - Indications of severe abrasion
    - No indication of inspections
    - In service about 14 ½ years
- No performance difference expected for Type 3 tanks in same conditions
End of Life Performance

- Some LC tanks have reached end of 15-year life
- No indication of problems with permeation or strength loss
- LC cylinders were tested after 9 years of service (323,348 miles = 520,380 km)
  - Five tanks passed visual inspection, proof and leak test
  - One tank cycled 45,000 times, then proof and leak, then burst, passing all tests, no evidence of strength loss
  - One tank dissected, no evidence of deterioration, liner tensile test, cold impact test, and $t_g$ test showed no signs of deterioration
  - One tank permeation tested, passed NGV2 requirements, no evidence of deterioration
Cylinder Certification

- Cylinders have been qualified to a number of different standards for different applications:
  - Vehicle fuel containers
  - Transportable cylinders and tubes
  - Stationary pressure vessels
- Each application also falls under a regulatory authority
- Authorities vary from country to country
- Independent agencies are often involved in qualification testing and approvals
Vehicle Fuel Containers

- **Standards include:**
  - ANSI/CSA NGV2
  - ISO 11439
  - SAE J2579
  - CSA B51 Part 2
  - ISO/TS 15869

- **Regulations include:**
  - DOT–NHTSA FMVSS 304
  - TC 301.2
  - ECE R110

- **Issues:**
  - World-wide acceptance of consistent standards and regulations for CNG
  - Hydrogen standards and regulations are under development
  - Significant technical issues are being debated prior to development of global technical regulations for hydrogen fuel containers
Transportable Cylinders and Tubes

- Standards include:
  ISO 11119-3  
  EN 12245  
  ISO 9809  
  ISO 7866  
  ISO 11120  
  Fuel container standards  
  Draft composite standards in development  
  Agency standards

- Regulations include:
  DOT–PHMSA 49 CFR, Special Permits  
  ADR/RID TPED

- Issues
  ◦ Transportation standards and regulations have been the slowest to adopt new technologies and approaches
  ◦ UN COE (Orange Book) has a goal of globally harmonized standards, but national and regional regulations inhibit progress
  ◦ Size and pressure are limited in some standards and regulations, but Special Permits and Approvals may be an option
Stationary Pressure Vessels

- Standards include:
  - ASME BPV Code
  - CSA B51 Part 3

- Regulations include:
  - US/State Building Codes
  - ADR PED

- Issues:
  - ASME Section VIII Div. 3 and ASME Section X have been updated for high pressure hydrogen storage
  - Vehicle fuel container standards have been accepted
  - Special Permits are common
  - Approvals are required in every jurisdiction used in US
Hydrostatic test has been the tradition
NDE methods are gaining favor
  ◦ Ultrasonic
  ◦ Acoustic emission
Visual inspection is widely accepted for fuel containers
In–situ NDE may offer benefits, but must be cost effective
Inspection of transportation and stationary vessels is generally required legally
Inspection of fuel containers is often voluntary
Composite cylinders have been in use over 50 years.

Cylinders are used for a number of different applications:
- Vehicle fuel containers
- Transportable cylinders and tubes
- Stationary pressure vessels

Pressure vessels and cylinders are highly regulated.

Approval process is complicated overall.