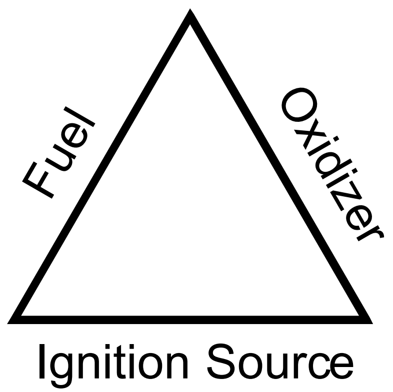
Polymer Matrix Composite Material Oxygen Compatibility

Marshall Combustion Research Facility
Materials and Processes Laboratory
Marshall Space Flight Center

- Problem Statement:
  - New Launch Vehicles require lightweight structures to achieve design goals
  - Polymeric Composite materials are being used in applications where lightweight structures are needed
    - Composite materials have been used successfully in many times:
      - Liquid Hydrogen Tank
      - Propellant Feedlines
      - Shroud Structures
      - Intertank Structures
  - Potentials weight savings for use of composite materials for Liquid Oxygen (LOX) tank structures is on the order of 25% weight reduction when compared to AL2219

- All materials must be evaluated for oxygen compatibility
- Materials exposed to elevated oxygen concentration and pressure possess and increased combustion hazard
- **Oxygen Compatibility**: The ability of a material to coexist with oxygen and potential ignition sources with an acceptable degree of risk.
- **Fire Triangle** - Combustion to occur, three factors must be present:
  - Fuel
  - Oxidizer
  - Ignition Source



- Materials Testing
  - Because of the present difficulties in analysis for oxygen compatibility, we rely on testing to determine the oxygen compatibility of a material
  - Credible ignition sources are tested to determine the sensitivity of the material to ignition
- Two Standard Tests for Oxygen Compatibility
    - Per the requirements of NHB 8060.1C, Flammability,Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion
  - Mechanical Impact (Test 13)
  - Upward Propagation (Test 17) also known as “Promoted Combustion”

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- Mechanical Impact (Test 13)
  - Striker pin transfers energy from 20 lb plummet dropped from 43.3 inches
  - Success criteria, 0 reactions out of 20, or if one reaction occurs, 40 additional tests with no reaction, 72 ft-lbs (98J)
  - Composite materials generally fail
  - Advantages:
    - Large Database
    - History of application
    - Fast
    - Inexpensive
    - Small amount of material required
    - Can be used as a relative ranking method

- Example of a typical composite material failure following mechanical impact in LOX
- Failure criteria includes:
  - Audible report
  - Flash
  - Visible charring of sample cup, striker pin, or sample
- Test is conservative, 72 ft-lbs is a large amount of energy
- IM7/8552 has been tested for damage tolerance, and energies greater than about 2 ft-lbs caused cracking that was significantly permeable

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- Promoted Combustion Test (Test 17)
  - Test determines the relative flammability of a material in 100% GOX.
    - Samples are 12” x 1/8”dia. “rods”
    - Materials burning less than 6” at the maximum use pressure are given an “A” rating
    - Samples are ignited by aluminum “promoter” and pyrofuse wire (aluminum-palladium)
    - A minimum of 5 samples are tested

- Mechanical Impact results
  - Many composites readily fail the mechanical impact test, often failing at low impact energy levels of 10-20 ft-lbs
  - Some materials are passing at higher energy levels, even as high as the 72 ft-lb requirement, however these results are from a limited amount of data
- Promoted Combustion results (Test 17)
  - Test 17 determines the relative flammability of materials in GOX at ambient temperature at a specified pressure
  - All composite materials fail this test readily at their intended use pressures
  - The consequence of failure (ignition), the tank would be fully consumed, and fail catastrophically
- Alternate Approach
  - Evaluate component design, relative risks and potential ignitions sources
  - Test composite materials for relative risk

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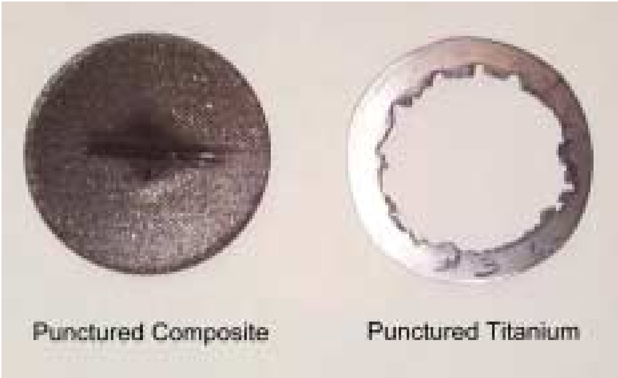
- External Puncture Test
  - Punctures a disk of material 2.36” dia.
  - Punctures Outside to Inside
  - Liquid Oxygen on top of sample
    - LN2 jacket maintains -320°F
  - Pressures up to 100 psia
- Performance
  - Titanium, severe reactions
    - Samples Combust, Audible Report
  - Polymer matrix composite materials
    - No reactions to date



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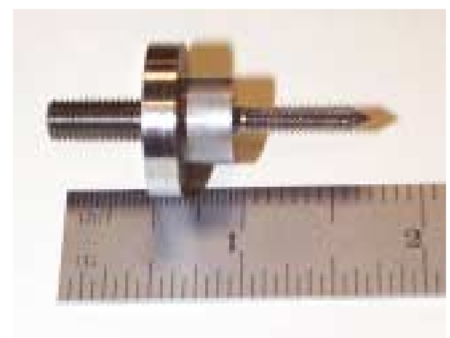
- Internal Puncture Test
  - Punctures a disk of material 2.35” dia.
  - Punctures Inside to Outside
  - Liquid Oxygen on top of sample
    - LN2 jacket maintains -320°F
  - Pressures greater than 100 psia
- Performance
  - Titanium, severe reactions
    - Samples Combust, Audible Report
  - Polymer matrix composite materials
    - No reaction to date
- Results are the same as External Puncture



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- Electrostatic Discharge
  - Test Determines whether a spark is a credible ignition source
  - The system is capable of delivering a spark of 5000V, with an energy of 112.5J
  - Samples were tested of various thickness, ranging from 0.006” to 0.125”
  - Only one composite material has failed this test
  - Currently only ambient pressure tests

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- Friction (Low Speed Friction)
  - Test determines the relative ignitability of composite materials when heated by friction while immersed in LOX
  - Well over 100 tests have been completed to date in both LOX and GOX, using a modified drill press
  - One sample is held stationary, and one sample is rotated in sample holder placed in the drill chuck, data measured included axial load (lbs) and stationary sample temperature using an embedded thermocouple
  - Samples reached maximum temperatures exceeding 600°F, this exceeds the maximum use temperature of the composite (~350°F), the composite samples disintegrated during the test
  - Samples showed no signs of reacting with the liquid oxygen, faint burn smell existed after the test

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- Pyroshock Sensitivity

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Test Method	Titanium	AL 2219	Composites
Reaction Frequency at 72 ft-lbs	19-60%	<10%	~85%
Impact Energy Threshold (ft-lbs)	15-20	72	10-40
Upward Propagation Threshold Pressure	<1 psi	<30 psi	<14.7 psi
Shock Sensitivity	Very High	Very Slight	Very Slight
Puncture Sensitivity	Very High	Unreactive	Unreactive *
Spark Sensitivity	Reactive	Unreactive	Very Low
Vibration Sensitivity	Slight	Slight	Low **
Frictional Heating Sensitivity	High	Low	Low *

* Limited number of tests

** Per testing performed by McDonnell Douglas

- Results
  - Titanium (found to be unsuitable for LOX tank applications)
    - High sensitivity to mechanical impact
    - Sensitivity to pyroshock
    - High sensitivity to puncture
    - Low pressure for sustained combustion
  - Aluminum (the standard LOX tank material)
    - Performs well on most tests with the exception of Promoted Combustion
  - Polymer Matrix Composites (better than Titanium, and worse than Aluminum)
    - Mechanical Impact - wide variability (10 ft-lbs to 72 ft-lbs)
    - Puncture Acceptable (External and Internal)
    - Electrostatic Discharge Acceptable
    - Friction Acceptable
    - Pyroshock Acceptable
    - Particle Impact Acceptable (WSTF)
    - Adhesive Failure hasn't caused ignition (WSTF)

- Future Work
  - Continue to refine Hazard Analysis
  - Test new credible ignition sources
  - Additional Coupon Tests
    - Elevated Pressure ESD
    - Elevated Pressure Friction
    - Electrical Overload
  - Push Oxygen Compatibility Testing beyond “Coupon Level”
    - Vibration testing of small bottles
      - Boeing (McDonnell Douglas) has demonstrated this on one bottle
    - Burst Tests with small bottles

- LOX Tank Design Recommendations
  - Goal is to lower the risk by management of the “Fire Triangle”
    - Fuel
      - Choose the most compatible materials that are suitable
      - Keep the composite cold
      - Liners?
    - Oxygen
      - Keep the oxygen as cold as possible
      - Inert gas pressurant system, such as helium
    - Ignition Sources
      - Avoid objects in the tank that can cause mechanical impact
      - Design to minimize other potential ignition sources

- Conclusions
  - Carbon Fiber / Polymer Matrix Composite Materials look promising as a material to construct LOX tanks
  - Based on mechanical impact tests the risk will be greater than aluminum, however the risk can probably be managed to an acceptable level
  - Proper tank design and operation can minimize risk
  - A risk assessment (Hazard Analysis) will be used to determine the overall acceptability for using polymer matrix composite materials
    - Note: A individual Hazard Analysis must be performed on each and ever LOX tank design to evaluate the relative safety of design and operation