

# Metal Mate



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## High Pressure Composite Cylinder



## Fuel tank technology

- 4 basic type of tank design
- Which design to use depend on need to reduce weight and how much can pay
- All design have equivalent safety, as all meet requirements of same standards

# Cylinder Types

**Type 1** – All Metal ( Aluminum or Steel )

- Cheap but heavy



**Type 2** – Metal liner reinforce by composite wrap ( Glass fiber ) around middle ( “Hoop wrapped” )

- Liner take 50% and composite take 50% of stress cause by internal pressurization
- Less heavy but more cost



# Cylinder Types

**Type 4**— Plastic liner reinforce by composite wrap around entire tank ( “Full wrapped” )

- Entire strength of tank is composite reinforcement
- Light weight but expensive



# Cylinder Types

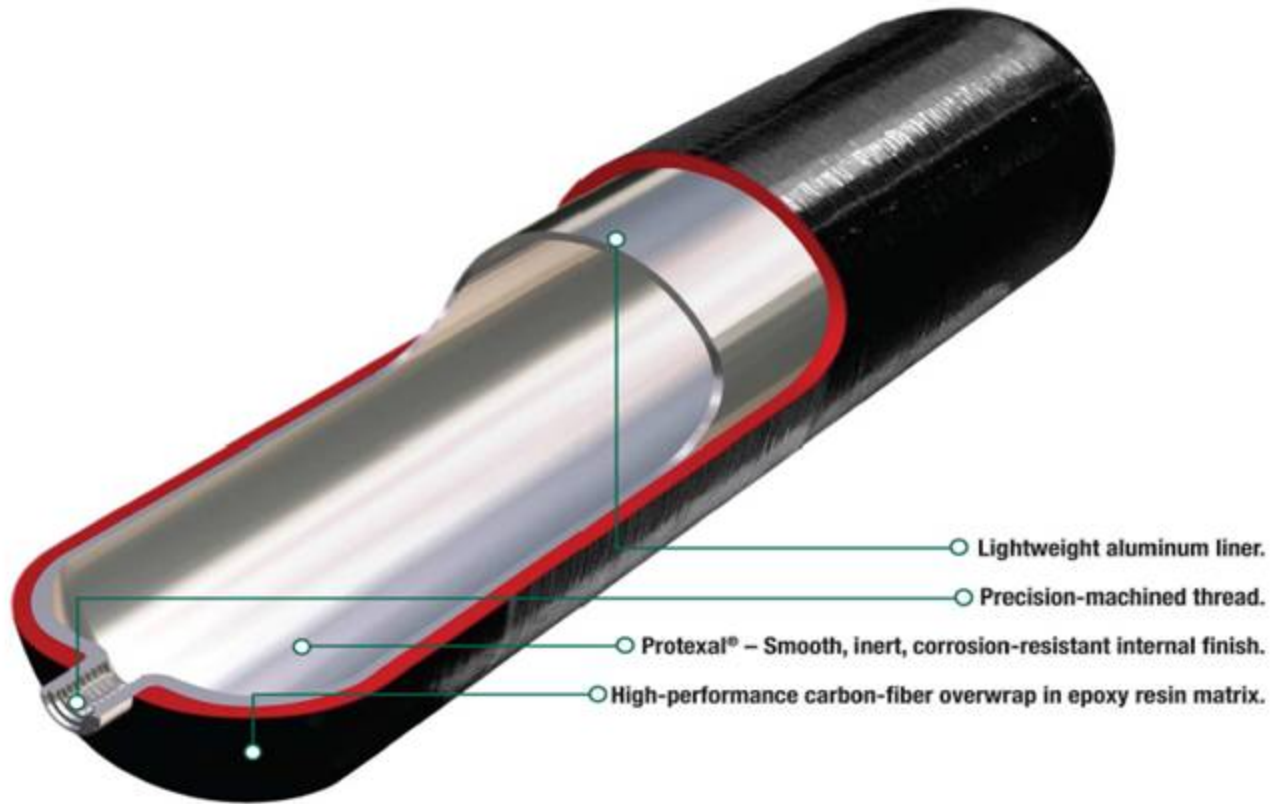
**Type 3**— AL liner reinforce by composite wrap (Glass fiber and Carbon fiber ) around entire tank ( “Full wrapped” )

- Liner take small amount of stress
- Light weight but expensive





## Metal Mate : Type 3 CNG cylinder



Type-3 aluminium-lined fully wrapped composite CNG cylinder.

## Liners for type 2 & type 3

- **Metal liners feature a long history of trouble-free safety.**
  - More than 40 years use.
  - Seamless with no welds
  - Impermeable and tough
  - More than 5 million in service.
  - Superb safety record.
  
- **Major Types and Liner Materials**
  - ***Hoop wrap Type 2***
    - 4130 Steel or 6061-T6 Aluminum
  - ***Full wrap, or Type 3***
    - 6061-T6 aluminum



Commercial style liner



Aerospace style liner

# Metal Selection Decision Matrix

Material	Steel 4130	Aluminum 6061-T6	Titanium TI-6AL-4V
Yield Strength, MPa	720	276	880
Ultimate Strength, MPa	850	345	950
Modulus of Elasticity, Gpa	200	68.9	113.8
Minimum Elongation, %	20	10	14
Density	7.8	2.7	4.4

- **Steel is good for type 2 hoop-wrapped cylinders**
  - **For Type 3: Density is 2.9 times greater than aluminum**
  - **To save weight, thickness must be <30% that of aluminum liner thickness; too difficult and expensive.**
- **Aluminum 6061-T6 is a good choice for Type 3 cylinders.**
  - **6061 is resistant to sustained load cracking and stress corrosion.**
  - **6351 and 7000 series aluminum are not recommended because of problems with sustained load cracking and stress corrosion.**
- **Titanium is a good choice for aerospace pressure vessels**



# Technical Differences

Feature	Steel & Aluminum	Full wrap composite
Stress analysis	Simple classical equations. Easy to design and for inspectors to verify	Difficult. No classical equations. Non-linear behavior must be analyzed. Computer methods required. Inspector verification difficult
Size effect	Metal strength constant no matter size	Size is big effect: larger diameter or thickness, lower fiber strength.
Material strength in burst testing	Strength determined from simple, cheap tensile testing.	Fiber strength determined only from pressure vessel burst tests. Strand tensile test meaningless.
Fatigue life calculations	Metal fatigue life can be designed from standard engineering handbook data	Cycle testing to leakage required plus statistical analysis. Standard handbooks don't apply
Statistics	Not important for design	Statistical analysis of test data is critical for design
Processing	Little effect on metal strength or other test performance.	BIG effect on fiber strength and pressure cycle life: fiber tension, epoxy properties, wrap pattern sequence, oven cure, autofrettage etc.

**Composite cylinders require different approach, more data, and more care.**

# Plastic liner versus Metal liner

## Plastic

### ✓ *Advantages*

- Less expensive liner
- Lighter weight
- Longer fatigue life
- Corrosion resistant

### ✓ *Disadvantages*

- Prone to leakage
- Permeable to gases
- Less damage resistant
- Low temperature vulnerability
- Difficult adhesive bond between composite/liner

## Metal

### ✓ *Advantages*

- Longer safe history
- Seamless leak proof design
- More damage resistant
- Impermeable
- Non flammable

### ✓ *Disadvantages*

- More expensive in large sizes.
- Specialized fabrication process
- Lower fatigue life

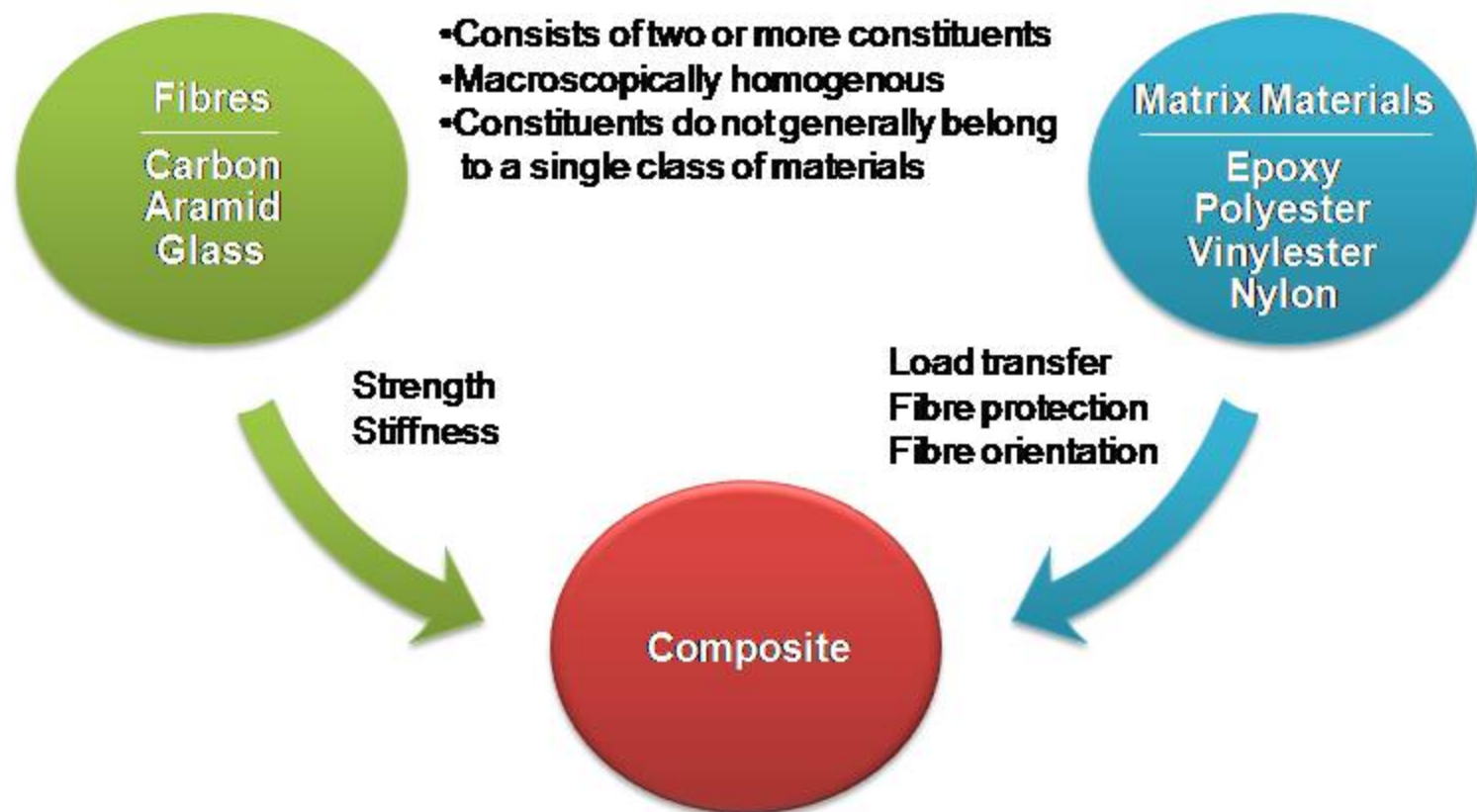
# Comparison of Different Type

- **Simple rule:** Composite cylinders will always cost more than metal cylinders.
- **Approximate cost comparison**
  - **Types 3 and 4:** most expensive, both sell for similar prices
  - **Type 2:** approximately 40% of cost of Type 3 & 4
    - ✓ Cost of Type 1 plus a little glass or carbon fiber
  - **Type 1:** Least expensive
- For CNG cylinders – Type 1 and Type 2 sell in far larger quantities than Type 3 or 4.
- **Weight comparison**

Type of cylinder	Service Pressure (bar)	Water Capacity (Lts)	Empty Weight (Kg)
Type 1	200	100	110Kg
Type 2	200	100	80Kg
Type 3	200	100	33kg
Type 4	200	100	33Kg

# What's Composite Material ?

## Definitions of “Composite material”





# What's Carbon Fiber ?

## Definitions of “Carbon fiber”

✓ is a material consisting of extremely thin fibers about 0.005–0.010 mm in diameter and composed mostly of carbon atoms.

✓ A high-performance carbon fiber made from a poly-acrylic-nitrile (PAN) precursor material

✓ Carbon fiber is lighter than aluminum, stronger than steel, and very expensive material





# Type of Carbon fiber

## Two types by Raw Material

### 1) PAN Type Carbon Fiber

- A type of the fiber, produced by carbonization of PAN precursor (PAN: Polyacrylonitrile)
- Having high tensile strength and high elastic modulus, extensively applied for structural material composites in aerospace and industrial field and sporting / recreational goods.



### 2) Pitch Type Carbon Fiber

- Produced by carbonization of oil/coal pitch precursor, having extensive properties from low elastic modulus to ultra high elastic modulus.
- Fibers with ultra high elastic modulus are extensively adopted in high stiffness components and various uses as utilizing high thermal conductivity and / or electric conductivity.

# Fiber comparison

Type	Advantages	Disadvantages
Glass Fiber	<p>Inexpensive and easy availability</p> <p>High impact strength</p> <p>Well proven in millions of pressure vessels</p>	<p>Lowest strength</p> <p>Produces heavy cylinders</p> <p>Damaged by acid and sustained loads</p>
Aramid	<p>Low density and lightweight</p> <p>High impact strength</p> <p>Used in many pressure vessels</p>	<p>Availability is difficult, expensive</p> <p>Lower strength than carbon fibers</p> <p>Affected by moisture</p>
Large Tow Carbon fiber	<p>Lowest cost carbon fiber</p> <p>Good for Type 2 &amp; Type 3 CNG cylinders</p> <p>Unaffected by chemicals or sustained loads</p>	<p>Lower strength produces heavier SCBA cylinders and heavier Type 4 cylinders</p>
Toray T700 carbon fiber & similar	<p>Excellent strength, impact, &amp; environmental resistance</p> <p>Most popular choice for gas cylinders</p>	<p>Price is volatile, high or low depending on market conditions.</p> <p>More expensive than large tow carbon</p>
Zylon PBO	<p>High impact resistance</p> <p>Same strength &amp; modulus as carbon fiber</p> <p>Low density – very lightweight</p>	<p>Less data for characterization</p> <p>Very Expensive</p>

# Tao 道 of Composite Cylinders



**Fiber are like “Rope”  
They are strongest when straight  
No Knot or edges to interfere  
with straight path**

- **Design and manufacturing must be tailored to keeping straight fibers.**
- **Fiber strength and pressure cycle life can increase or decrease from only small differences in processes or materials.**

**Even when the stress analysis says there will be no difference.**

- **THICKER composite laminates amplify flaws – not reduce them.**
- **Design and processing must be understood from a “micro mechanics” level**
- **Minimize wrinkles or uneven surfaces for the fibers.**
- **Must keep statistical data base of all burst tests and pressure cycle tests.**



# Application of CF Composite



- Composite are important when light weight is needed.
- Up to 70% Weight Savings from Steel .**

## Application of Carbon fiber Composite

- ✓ Aerospace pressure vessels
- ✓ Firefighters Breathing Systems
- ✓ Aircraft
- ✓ Windmill
- ✓ CNG and Hydrogen for Taxis and Buses
- ✓ Portable home oxygen therapy





# Merits of Type 3 CNG cylinder

👍 Safety ("Leak before burst")

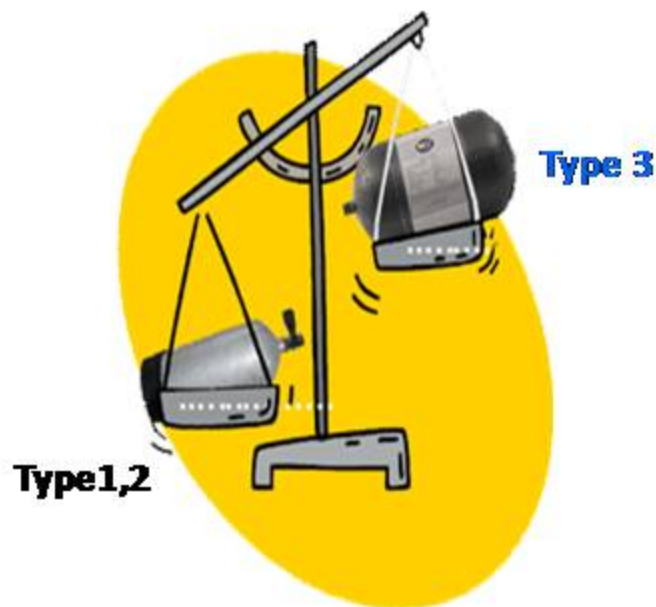
👍 Highest Burst Pressure

👍 Anti-corrosion and long fatigue life

👍 70% lighter than steel cylinder (Type 1)

👍 50% Lighter than Type 2

👍 More stable than Type 4 (No permeation)





# Safety : Leak Before Burst ( LBB )

## What is Leak Before Burst mean ?

- Leak before burst describes a pressure vessel designed such that a crack in the vessel will grow through the wall,
- Allowing the contained fluid to escape and reducing the pressure,
- Prior to growing so large as to cause fracture at the operating pressure.

## Type 3 : Highest safety of CNG cylinder

- The tank stay in service beyond design life (15 years) and experience excessive fill cycle
- It will only fail by leakage
- It is more reliable, leak-proof solution to gas containment.



# TYPE 1 CNG cylinder: Burst at Samutprakarn

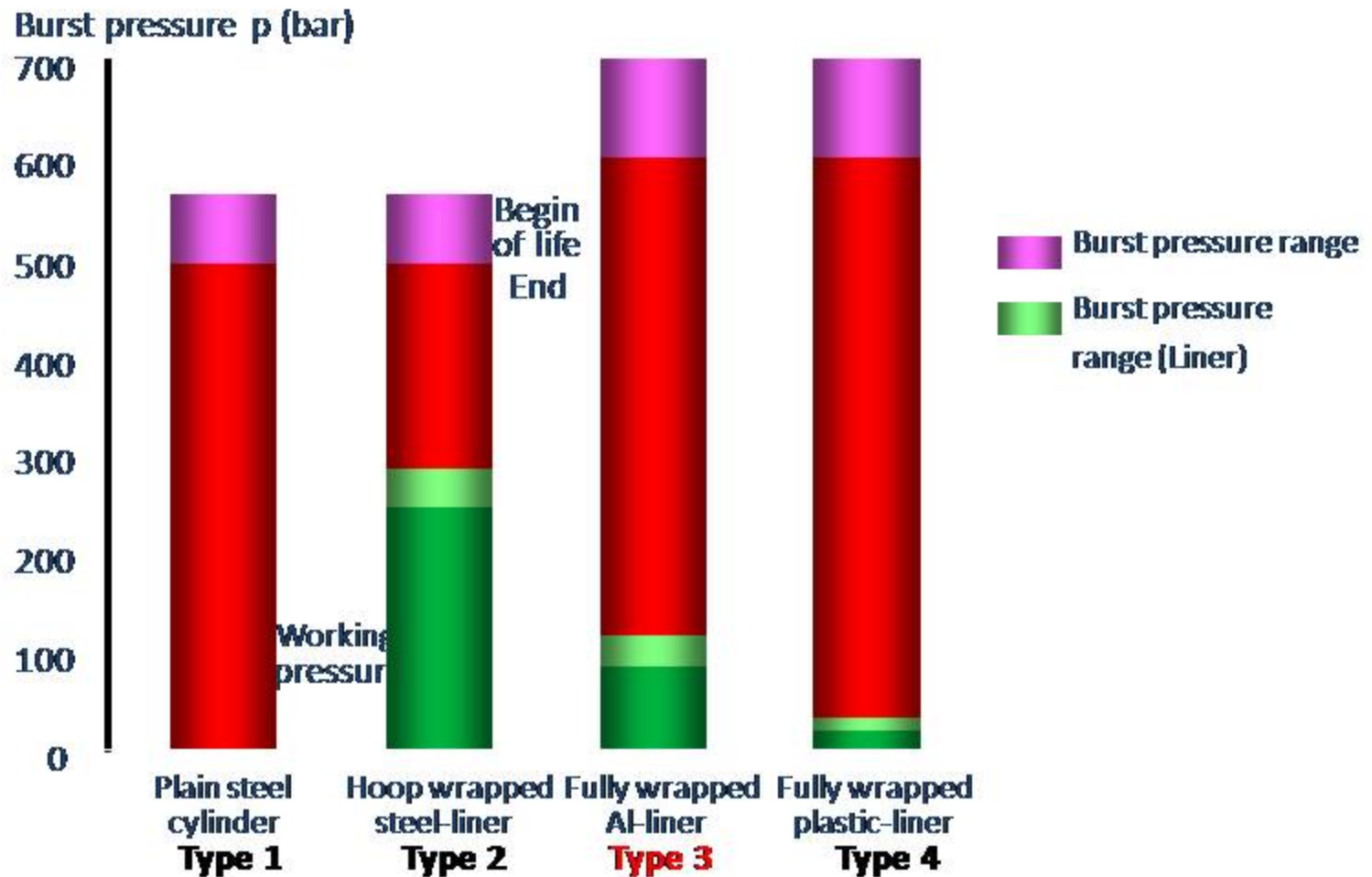


## TYPE 1 CNG cylinder: Burst





# Highest burst pressure



**Type 3 & Type 4 have the highest internal pressure reached in a CNG fuel container during a burst test at a temperature of 21 °C (70 °F) at 650 bar**

# Anti corrosion and fatigue life

## Corrosion

- Occur easily especially metal surface (Type 1)
- As the result, it involve loss of wall thickness
- Difficult to visual inspect inside the tank

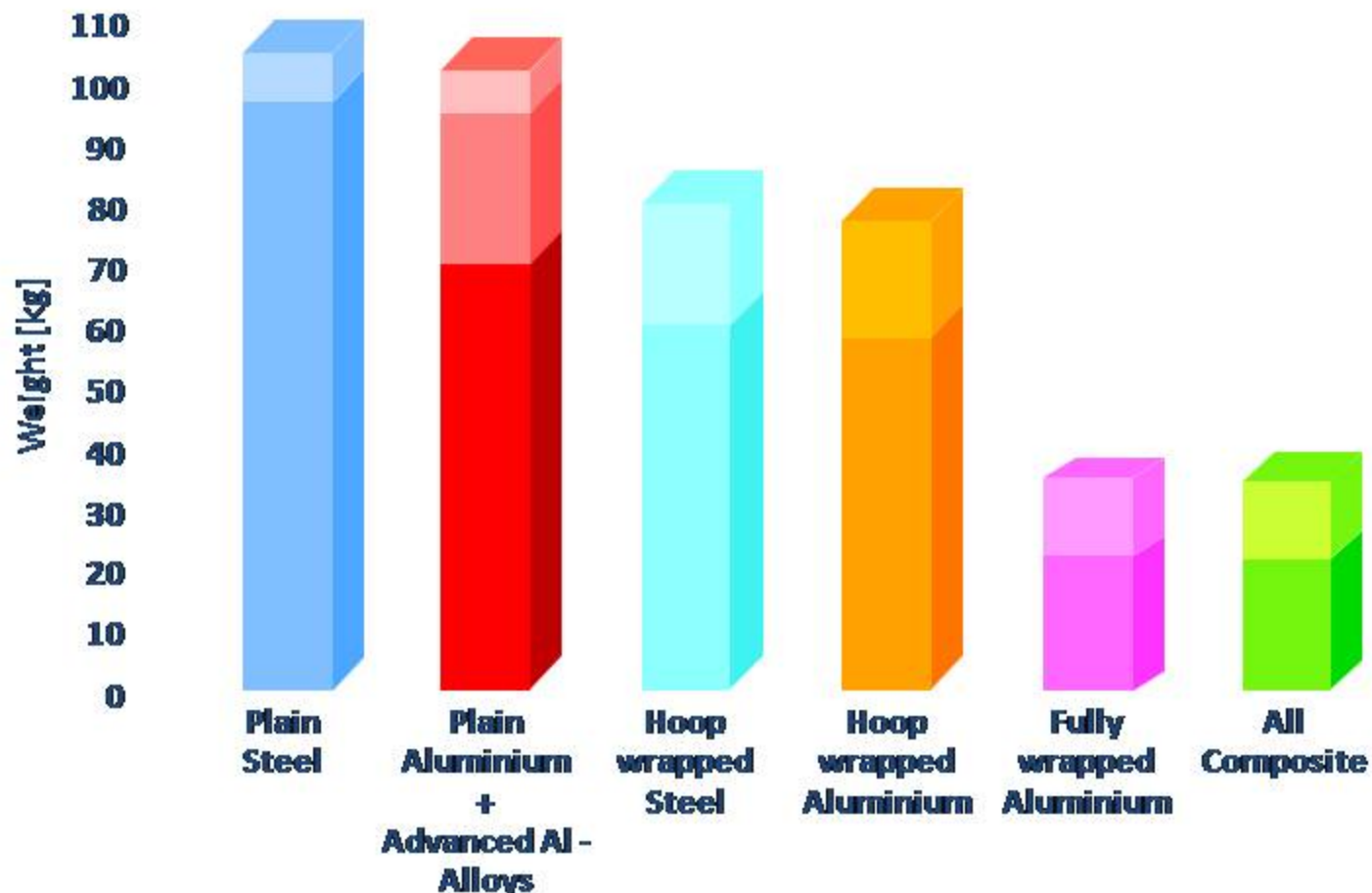


Corrosion significantly reduces the life span of cylinder

**Aluminum 6061-T6 is a good choice for Type 3 cylinders.  
A6061 is resistant to sustained load cracking and stress corrosion.**



# Lighter than Type 1 and Type 2



- Type 3 lighter than Type 1 **around 70%**
- Type 3 lighter than Type 2 **around 50%**

## Lighter than Type 1 and Type 2

### *Weight comparisons*

Type of cylinder	Service Pressure (bar)	Water Capacity (Lts)	Empty Weight (Kg)
Type 1	200	100	110Kg
Type 2	200	100	80Kg
Type 3	200	100	<b>33kg</b>
Type 4	200	100	31Kg

## More stable than type 4 ( No Permeation )

- Type 3 liner made from Aluminum
- Which is no permeation if compare to type 4
- Type 4 liner made from **High-density polyethylene (HDPE)** which is plastic material
- Nature of plastic **“Easy to permeable”**
- Difficult to visual inspection inside the cylinder



# METAL MATE

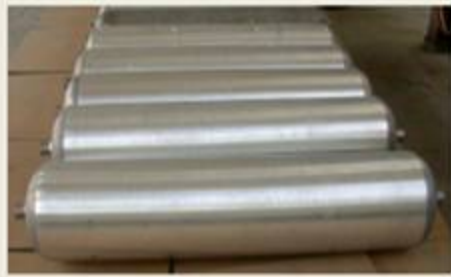
- Metal Mate emphasis its vision to be leader in alternative fuel storage industry
  - **First manufacturer** of CNG cylinder in South-East Asia.
- Metal Mate had invested in one of the world's most advance seamless aluminum liner production line and filament winding technology
- In order to produce ultra-light type3 CNG cylinder with a world class production capacity at **800 units/shift**



# Material of construction



Tubes –  
Steel or Aluminum



Liners – Steel or  
6061-T6 Aluminum



Liners – Plastic



Aluminum plate



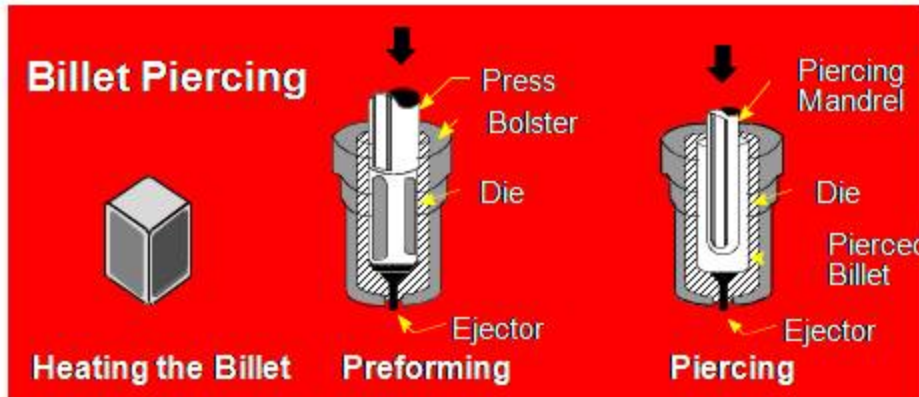
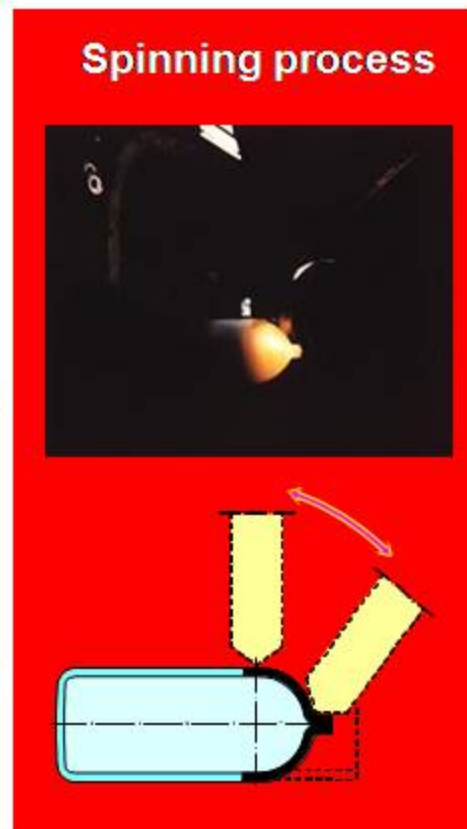
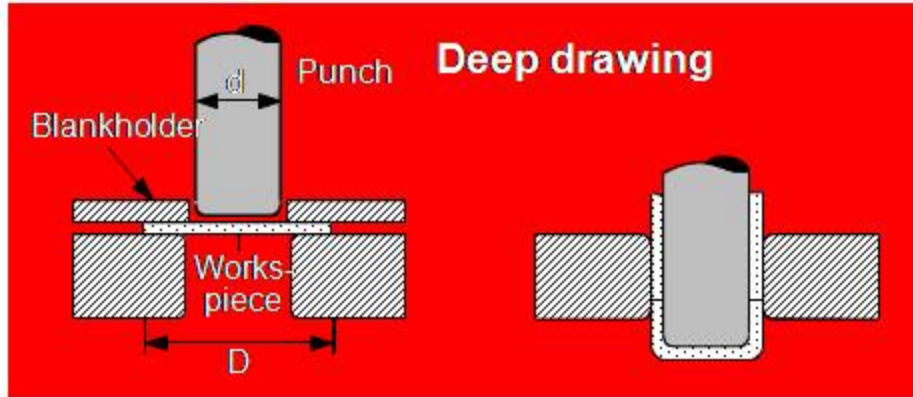
Aramid, Carbon, Glass Fibers



Filament winding carbon fibers/resin  
for fully-wrapped cylinders



# Manufacturing process : CNG cylinder



# Metal Mate: Manufacturing Process of Type 3 CNG cylinder

**AL coil**



**AL plate**



**Deep Drawing approach**



**Spinning Machine**



**Filament winding machine**





# ***PERFORMANCE TESTING***

- All CNG vehicle fuel container must meet the [Thai Industrial Standards Institute \(TIS 2311-2552\)](#)
- Qualification tests required by standards to ensure tanks and components will perform safely when subject to automotive service conditions



# Performance testing

## 1) Hydraulic Pressure cycle testing

- Test by used water instead of gas (easier to pressure cycle)
- Cycle time at least 15,000 times
- **Failure mode must leak not rupture**



## 2) Bonfire test

- To assure gas will vent before cylinder rupture when exposed to fire



# Performance testing

## 3) Gunfire testing



# Performance testing

## 4) Drop impact testing

- Drop impact test at height 180 cm.





# Performance testing

## 5) Burst testing

