Fibreglass composite gas cylinders

Glass fibre cylinders for hydrogen storage and distribution

A viable alternative to steel or carbon fibre

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Storage of hydrogen as a compressed gas is essential for hydrogen mobility applications and the distribution of hydrogen on the roads. Shipping of compressed hydrogen has also been proposed for short and medium distances. In all cases, robust gas cylinders are required to safely contain the hydrogen.

When designing a passenger car, space is at a premium. A good driving range is also expected. Therefore, high pressure storage of hydrogen is required and the standard pressure on board for a full tank is 700 bar.

Hydrogen distribution also requires a large quantity of hydrogen to be stored on the trailer. If more hydrogen can be transported in one journey, then fewer journeys, fewer vehicles and fewer drivers are required. Therefore, high pressure hydrogen storage favours economical compressed hydrogen distribution operations.

The capital cost of hydrogen storage tanks must also be considered. The highest-pressure storage in current operation is offered by Type 4 carbon fibre composite cylinders. However, this is also the most expensive type of storage tank in common use.

On the other hand, glass fibre Type 4 composite cylinders offer many of the benefits associated with Type 4 carbon fibre cylinders, albeit it at a lower pressure. However, they are significantly less expensive to build.

As glass fibre technology matures and the strength of the material increases, it may become a cost-effective alternative to carbon fibre in some cost-sensitive hydrogen storage and distribution applications.

Compressed natural gas for mobility applications

Worldwide, there are fewer than 500 hydrogen refuelling stations to support hydrogen powered vehicles. This technology is still in its infancy. On the other hand, in Italy alone, there are more than 800 compressed natural gas (CNG) refuelling stations for more than one million CNG-powered vehicles. Broadening that to Europe, there are 2,700 CNG refuelling stations.

At 250 bar, CNG has a volumetric energy density 35% more than compressed hydrogen gas at 700 bar. This puts pressure on hydrogen storage to be at a much higher pressure than CNG, to achieve similar driving range and energy storage onboard the vehicle.

This difference has led to CNG storage typically being in Type 4 composite cylinders with a glass fibre wrap, whereas hydrogen storage cylinders have evolved to use the more expensive carbon fibre wrap around Type 3 or Type 4 cylinders.

Despite the differences in energy density, compressed hydrogen storage may be able to learn from CNG storage. The maturity and scale of CNG tank production can also be leveraged to accelerate the availability of Type 4 composite cylinders for hydrogen.

Knights in shining armour and bullet proof vests

When knights rode their chargers into battle, they were clad in steel armour. It was heavy and relatively ineffective. Type 1 cylinders are made of steel and are also heavy and comparatively ineffective when compared to modern Type 4 composite cylinders.

A full-sized compressed hydrogen distribution truck using Type 1 steel ▸

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cylinders with a vehicle weight of 40 tonnes can carry around 300kg of hydrogen. This means that less than 1% of the total vehicle weight is the hydrogen payload. Put another way, 99% of the energy and time invested in the logistics operation is required to move steel on the roads. It is extremely wasteful.

Modern knights – soldiers and police officers – are not clad in steel armour. They wear lightweight, flexible body armour made of Kevlar® fibre. The use of composite materials has transformed the way in which soldiers' lives can be protected on the battlefield. Similar lessons have been applied to compressed gas cylinders.

Modern Type 4 carbon fibre composite compressed hydrogen distribution vehicles can transport a payload of around 1 tonne of hydrogen gas, about three times more than the more traditional Type 1 vehicle. It is still only circa 2.5% of the payload, but a significant improvement on the older technology.

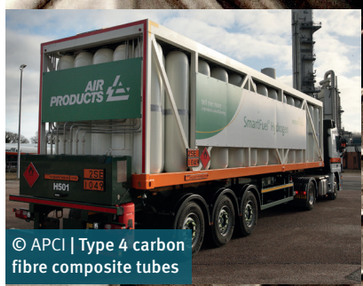
Making glass fibre more like Kevlar® and carbon fibre

Kevlar® is a para-aramid fibre. Its strength lies somewhere between glass fibre and carbon fibre. Lightweight emergency oxygen cylinders in aircraft have been constructed using a Type 3 design with a Kevlar® wrap. Since it has a higher tensile strength than glass fibre, it can accommodate higher pressures. On the other hand, it is more expensive than glass fibre.

Glass fibre is a broad description covering a wide range of glasses. There are many types of glass, each with properties aligned to the application. Some glass is brittle but chemically resistant. The property of glass fibre that is most desirable for use in compressed gas cylinders is a high single fibre tensile modulus – meaning that the fibre is strong.

E-Glass is commonly used for the construction of fibreglass components such as canoes or car bodies. It is an alumino borosilicate with around 20%

Kevlar is used to make bullet proof vests



© APCI | Type 4 carbon fibre composite tubes


Protective steel armour


Mercedes-Benz eCitaro G Range Extender Type 4 carbon fibre hydrogen


Bullet proof vest with Kevlar fibre

Aviation emergency oxygen cylinder

calcium oxide. However, S-Glass has the most suitable characteristics for use in high pressure compressed gas cylinders. It is an alumino silicate glass with circa 10% magnesium oxide content to replace the calcium oxide.

The development of glass fibres is ongoing. They are used extensively to manufacture wind turbine blades. Turbines have increased in size from only 50kW and 15m diameter 1980s to more than 150m diameter yielding up to 20 MW of power today.

As the size of the blades has increased, the requirements of the glass fibres used in their construction have become more demanding. Expansion of wind turbine production has also led to economies of scale working their way through the glass fibre industry.

The evolution of glass fibres in CNG and wind turbine applications will surely have a positive spill-over into high pressure compressed gas cylinder manufacture to yield high-performance, low-cost Type 2, 3 and 4 cylinders for hydrogen storage and distribution. gw

> "Its strength lies somewhere between glass fibre and carbon fibre"

The five types of compressed gas cylinder

The construction of compressed gas cylinders is categorised as Type 1, 2, 3, 4 or 5. The most common type of industrial gas cylinder is a **Type 1 cylinder**. It is of an all-metal construction, in essence, meaning that it is made from an alloy of either steel or aluminium. The typical working pressure of such cylinders is in the range of 200 to 300 bar.

Type 1 steel cylinders are used for medical oxygen, hydrogen, nitrogen, and carbon dioxide/argon welding gas mixtures. Type 1 aluminium alloy cylinders are required in some specialty gases applications where steel is not compatible with the gas mixture. Type 1 aluminium alloy cylinders are also used for medical oxygen to reduce the cylinder weight and increase the portability of the package.

A **Type 2 cylinder** builds on the Type 1 construction and adds a hoop-wrap of a composite material. A hoop wrap is also referred to as a body wrap and covers the vertical wall of the cylinder but does not enclose the heel, nor the shoulder. The composite wrap is generally glass fibre, although carbon or Kevlar® fibre is also possible. Type 2 cylinders are generally of steel construction. They are commonly used for very high pressure applications such as hydrogen storage at 900 bar on a hydrogen refuelling station.

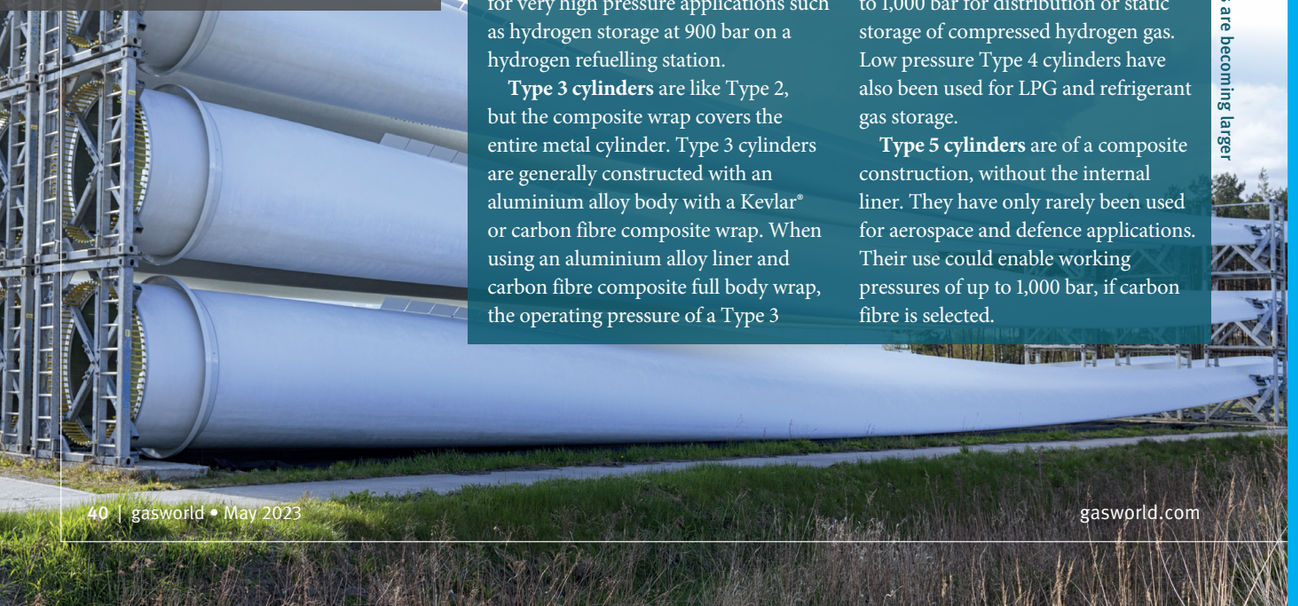
Type 3 cylinders are like Type 2, but the composite wrap covers the entire metal cylinder. Type 3 cylinders are generally constructed with an aluminium alloy body with a Kevlar® or carbon fibre composite wrap. When using an aluminium alloy liner and carbon fibre composite full body wrap, the operating pressure of a Type 3 cylinder is generally 350 or 700 bar – the standard pressures for onboard hydrogen storage on trucks and buses or passenger cars.

With a carbon fibre wrap, Type 3 cylinders are used for onboard hydrogen storage in mobility applications where a light-weight cylinder and high-pressure hydrogen storage are required. An additional benefit of choosing this cylinder type is that the heat that is generated when hydrogen is rapidly filled into the car storage tank can be dispersed rapidly by the aluminium cylinder body. The Kevlar® wrap on an aluminium alloy body has been used for aviation oxygen storage.

Type 4 cylinders are of a similar construction to the Type 3 design. However, the liner is a plastic material, not a metal. Either carbon fibre, Kevlar® or glass fibre composite material is used as the wrap. The liner is generally made from polyethylene or polyamide. The use of PET as a liner material has also been proposed.

Where glass fibre composite wraps are used, the working pressure of a Type 4 cylinder is generally up to 250 bar for onboard storage of CNG in mobility applications. Where carbon fibre composite is used, the working pressure of a Type 4 cylinder can be up to 1,000 bar for distribution or static storage of compressed hydrogen gas. Low pressure Type 4 cylinders have also been used for LPG and refrigerant gas storage.

Type 5 cylinders are of a composite construction, without the internal liner. They have only rarely been used for aerospace and defence applications. Their use could enable working pressures of up to 1,000 bar, if carbon fibre is selected.



Wind turbine blades are becoming larger