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Lightweight multilayer composite structure for hydrogen storage tank

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ABSTRACT

Composite pressure vessel has been applied by NASA for the first time. Safe low-cost efficient composite hydrogen-storing device is a key technique affecting the generalization and application of hydrogen energy. By combining the shear theory and based on the highly heave-stable shear behavior shell structure lightweight design, this paper describes researches on the lightweight design of pressure vessel lining and, on the basis of completing the numerical analysis of hydrogen storage tank, extracts its stress isogram, achieving the conformity or tangency of fiber weaving type with stress load isoline and accomplishing lightweight design of the tank and reduced production cost. The method herein can be further generalized to the storage of hydrogen energy and pipe component design.

Introduction

A composite pressure vessel normally consists of composite reinforcing layer, lining layer and protective layer. Over the latest years after application of composite pressure vessel by NASA for the first time, its application fields have been constantly developed and extended [1–3].

Because of the constant differentiation of technologies, the role played by lightweight design and lightweight material is becoming more and more important in fields like aeronautics/astronautics, automobile manufacturing and construction. The benefit is obvious: lightweight can save material on the one hand and save energy in the power system of kinetic structures on the other hand. For large-scale utilization of hydrogen energy, people must address themselves to such key techniques as the making, storage and transport of hydrogen and hydrogen energy conversion. Transport of hydrogen represents a very large part of the entire hydrogen energy supply chain in respect of economy, energy consumption and emission performance. For the generalization of hydrogen energy, therefore, there is an urge to study the lightweight design of hydrogen storage devices and meet requirements on their economy and safety [4–6].

By combining the shear theory, this paper describes researches on the lightweight design of pressure vessel lining and, on the basis of completing the numerical analysis of hydrogen storage tank, extracts its stress isogram, achieving the conformity or tangency of fiber weaving type with stress load isoline, attaining a digitalized 3D auto fiber placement technique, and accomplishing the lightweight design of the hydrogen storage tank and reduced production cost.

Multilayer structure and carbon fiber cross-ply lamination based hydrogen storage tank lightweight design

70Mpa high-pressure gas tanks are used on Toyota Mirai for hydrogen storage. Toyota Mirai carries two hydrogen tanks

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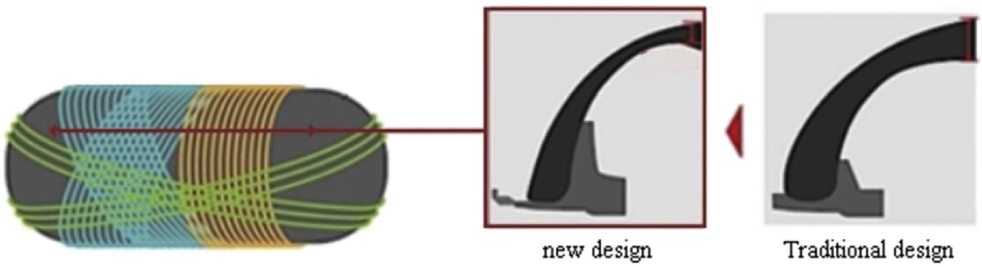

Fig. 1 – Carbon fiber reinforced plastics for Toyota Mirais hydrogen storage tank.

with internal volume of 122.4 L (front 60 L and rear 62.4 L) and total storing capacity of 5 kg.So the weight of fuel is actually not heavy and, on the contrary, the tanks are remarkably cumbersome. With the help of carbon fiber reinforced plastics (CFRP), Toyota Mirais vehicular hydrogen storage tanks attain shell lightweight. At the same time, the physical properties of various fibers can be brought into effective play through combined application of multiple fibers and different fiber weaving types to accommodate forces on different tank areas; hence 40% reduction of fibers used, as shown in Fig. 1.

To ensure driving safety on the premise of withstanding 700 atm, the hydrogen tanks have been designed to have a four-layer structure. The aluminum-alloy tank is lined internally with plastic lining and wrapped externally in a protective layer of carbon fiber reinforced plastics, with one more shock-absorbing protective layer of fiber glass material added outside that protective layer. Fiber grain on each of the layers has been additionally optimized, depending on different positions where it is on the tank, so that the fibers run along the direction of pressure distribution to enhance the effect of the protective layers.

This paper will analyze round-section hydrogen storage tanks with finite element software ANSYS. Since the tanks have a symmetrical structure, we just need a 1/4 model to save our calculation cost, with a tangible unit used as lining and shell unit as wound composite, as shown in Fig. 2. Data in Ref. [7] are used as tank parameters:

(1) Wound carbon fiber resin system: its tensile modulus is 135 GPa, compressive modulus is 108 GPa, tensile modulus in the vertical fiber direction is 8 GPa, shear modulus is 5 GPa, Poissons ratio is 0.3, tensile strength is 2,400 MPa, compressive strength is 1,000 MPa, shear strength is 76 MPa, and density is 1,800 kg/m^3;
(2) Metal lining material: E = 210 GPa, Poissons ratio is 0.3, density is 7800 kg/m^3, yield strength is 800 MPa, and tensile strength is 1100 MPa.
(3) Condition under pressure: the pressure vessels remain under internal pressure of 35 MPa.

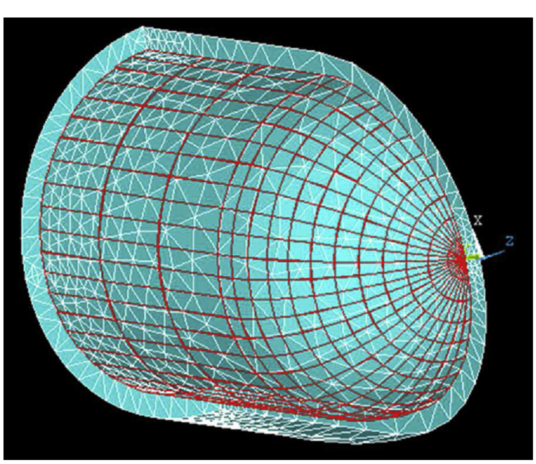

Fig. 2 – 1/4 finite element model of composite pressure vessel.

Achieving metal lining reinforcement with shear field theory

Mechanical properties of hydrogen storage tanks fiber composite have something to do with stress load direction and fiber orientation

Conventional containers are liable to heave for their shell structure style. To increase heave load and heave safety remarkably, braces or ribs can be used to diminish the main heave field. For the nodal line on the heave outline, these braces or ribs have sufficient stiffness. For shear load (as caused by the bending and twisting of lateral force), however, the stiffness and strength of rib lattice structure are often not great enough. To fill the gap, a layer of thin *shell* can be introduced to sustain the main shear stress load.

When the heave safety of the thin shell is increased, note that, although the heave field can be kept at a very small value by mounting braces, their bending stiffness and torsion stiffness may be just great enough to induce the nodal line on the heave outline. On the other hand, the lattice shape of rod structure is fairly sensitive to shear stress load and therefore addition of a layer of shell over the structure is of great benefit as it can sustain shear force (as caused by lateral force or torsion). Fig. 3 shows the effect of these two kinds of reinforcement; d) into which a) shell and the brace lattice comprised of b) longitudinal beams and c) ribs are combined has a highly heave-stable shear behavior shell structure [8].

Cylinder heave-proofing stability calculation and analysis

Cylinder stress can be solved by the section method, but not all the problems can. Helical seal head is an example, where the radius of curvature differs from point to point and stress inside the wall varies. Such problems can be solved only by