



# Containing the Future: 수소저장 안전기준 기술적 한계와 도전



## 수소자동차 국제기준 개발 및 국내 도입 현황

김형구\*

### The Status of International Vehicle Regulations on Hydrogen Fuel Cell Vehicles and Its Implementation in Korea

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**Key Words :** UN ECE WP.29(유엔 유럽경제이사회 자동차국제기준 조화기구), UN Regulations(UN 기준), UN GTR(UN 세계기술기준), HCFV(Hydrogen Fuel Cell Vehicles, 수소연료전기자동차), Liquefied Hydrogen Engine Vehicles(액화수소엔진자동차)

#### ABSTRACT

Since the establishment of the UN GTR No.13(Global Technical Regulation) for Hydrogen Fuel Cell Vehicles for passenger vehicles in June. 2013 in UNECE WP.29, the UN R134 for HFCV has also been established in accordance with UN GTR No.13 in 2014, and the phase 2 activities for amending of UN GTR No.13 has been started to expand applicable to large vehicles and improve performance requirements in 2020, and this activities were completed in June 2023, and now, the development of liquefied hydrogen engine vehicle requirements have begun after finishing phase 2 and is currently in the final stage. for reflecting all requirements of UN GTR No.13 phase 2, MoLIT are now proceeding to amend 'Notice for the Safety of Pressure Containers for Vehicles' with the goal of complete the promulgation of this notice within this year.

Therefore, the major recently established UN GTR No.13 Phase 2 and the current activities for introducing requirements for liquefied hydrogen engine vehicles in WP.29 and its implementation in Korea will be introduced. 2013년 6월, UN ECE WP.29에서 수소승용자동차에 대한 UN 세계기술기준(UN GTR No.13)이 제정된 이후, 2014년에 UN 세계기술기준을 반영한 UN 기준 No.134도 마련되었으며, 2020년부터 대형자동차로의 적용 대상 차종 확대 및 성능기준 개선을 위한 2단계 국제기준 개정작업이 시작되어 '23년 6월 개정을 완료하였다. 현재는 액화수소엔진 자동차 기준 개발활동을 시작하여 현재 마무리 단계에 있다. 국토교통부는 올해 안에 국토교통부 고시인 "자동차용 내압용기 안전에 관한 규정"의 개정 공포를 목표로 절차를 진행하고 있다.

이에 최근 WP.29에서 마련된 UN 세계기술기준 No.13의 2단계 기준 및 액화수소엔진자동차 기준 개발현황과 국내 도입 현황을 소개하고자 한다.

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## 나노클레이 혼합비에 따른 수소저장용기 라이너의 기계적 물성 연구

조재동\* · 남칠진\* · 허녕도\* · 신석철\*\* · 김성현\*\*\* · 서종덕\*

### Effect of Nanoclay Mixing Ratio on the Mechanical Properties of Hydrogen Tank Liners

Jaedong Cho\*, Chiljin Nam\*, Nyeongdo Heo\*, Seokchul Shin\*\*, Sunghyun Kim\*\*\*, Jongdock Seo\*

**Key Words :** Hydrogen tank(수소저장용기), Nanoclay(나노클레이), Gas permeation(가스 투과도), Hydrogen barrier property(수소 차단 성능), Mechanical properties(기계적 물성)

#### ABSTRACT

This study investigates the effect of varying nanoclay mixing ratios on the mechanical properties of polyamide 6 (PA6), a widely used liner material for Type IV composite pressure vessels in high-pressure hydrogen storage systems. Nanoclay, a layered silicate with a plate-like morphology, enhances the polymer's structural integrity by strengthening intermolecular interactions and introducing a microstructural barrier effect when well dispersed within the matrix. PA6 nanocomposites with different nanoclay contents were prepared using a masterbatch process and subsequently molded into specimens through injection molding. Tensile tests demonstrated that the addition of nanoclay improved tensile strength and modulus compared to neat PA6, particularly at optimal mixing ratios. This improvement is attributed to the plate-like nanoclay structure, which enhances stress transfer and stabilizes crystalline morphology. However, excessive nanoclay loading led to particle agglomeration, reducing dispersion uniformity and increasing property variation. The results confirm that precise control of nanoclay content is a key factor in improving both the mechanical performance and hydrogen barrier characteristics of PA6 liners, contributing to enhanced durability and safety of high-pressure hydrogen storage systems.

본 연구는 산업통상자원부(MOTIE)와 한국산업기술기획평가원(KEIT)의 “자동차산업기술개발”의 지원을 받아 연구한 과제입니다. (No. RS-2024-00507688)

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## Type IV 수소저장용기의 필라멘트 와인딩 장력에 의한 공압 인가 시점 분석에 관한 연구

김건우\* · 김혜원\*\* · 박한민\*\* · 박규환\*\*\* · 김한상†

### A Study on the Analysis of Pneumatic Pressurization Timing Induced by Filament Winding Tension in Type IV Hydrogen Storage Vessel

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**Key Words :** Hydrogen storage vessel(수소저장용기), Filament winding(필라멘트 와인딩), Tension(장력), Compressive load(압축 하중), Pneumatic(공압)

#### ABSTRACT

In filament winding, a key process in fabricating composite hydrogen storage vessels, fiber tension strongly influences laminate quality and mandrel stability. Direct evaluation of tension variation is costly and time-consuming due to complex fiber paths and contact conditions. To address this, an integrated process combining analysis and experiments was developed to quantitatively assess tension effects. The fiber path through the tensioner, resin bath, machine eye, and mandrel were modeled using geometric coordinates, and cumulative tension loss was calculated with the Capstan equation and effective friction coefficients. The model was validated by comparing predictions with pressure sensor measurements. A tension to compressive load conversion model was then applied to hoop and helical layers, while mandrel buckling limits were examined using theoretical equations and finite element analysis. From these results, pneumatic pressurization timing was determined based on cumulative compressive pressure. The proposed process and results enable optimized design of fiber tension, winding patterns, and pressurization timing, contributing to improved process reliability and development efficiency.

본 연구는 산업통상자원부(MOTIE)와 한국에너지기술평가원(KETEP)의 “신재생에너지핵심기술개발사업”의 지원을 받아 연구한 과제입니다. (No. RS-2024-00449107)

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## 고압수소에너지를 이용한 차량용 에너지회수 시스템 개발

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### Development of an Energy Recovery System for Vehicles Using High-Pressure Hydrogen Energy

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**Key Words** : High-Pressure hydrogen energy, Vehicles, Recovery system, CFD analysis

#### ABSTRACT

A hydrogen fuel cell vehicle consists mainly of a battery, a high-pressure hydrogen storage vessel, and an electric motor. The storage vessel is charged to 700 bar and supplies hydrogen to the fuel cell. Hydrogen compressed to 700 bar is reduced to 10–20 bar through a high-pressure regulator, and then to 1.5–3 bar through a low-pressure regulator before entering the fuel cell stack. To achieve 700 bar charging, hydrogen is compressed to 900 bar using a piston-type or diaphragm-type compressor and supplied to the vehicle tank via a dispenser at the refueling station. According to the SAE J2601 protocol, the tank temperature must remain below 85 °C; therefore, hydrogen is pre-cooled to below –40 °C to account for temperature rise during refueling. Compressing hydrogen from 200 bar (tube trailer) to 900 bar requires about 100 kW of energy, most of which is consumed in compression and cooling, equivalent to the energy needed for an electric vehicle to travel 400–600 km. During fuel supply, hydrogen pressure decreases from 700 bar to 1.5–3 bar, and most of the potential energy ( $\Delta P$ ) is lost as heat, vibration, and impact. Recovering only 20 percent of this 100 kW energy could extend the driving range by 80–120 km, significantly improving fuel efficiency. This study proposes an on-board hydrogen energy recovery system that reuses high-pressure energy released during decompression. A design and analysis program was developed to estimate recoverable energy according to system configuration, supported by a test apparatus and CFD-based validation. The developed program enables system design, control logic development, and energy recovery estimation. Based on the design results, a full-scale prototype will be fabricated and experimentally validated to establish an optimal configuration for a vehicle-integrated hydrogen energy recovery system.

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## 타입4 수소저장용기 PA6 라이너의 용착 공정 최적화를 위한 CT 분석

동권휘\* · 정근성\*\*

### CT-Based Butt-Fusion Quality Analysis for PA6 Liners in Type 4 Hydrogen Pressure Vessels

Kwon Hwi Dong\*, Geun Sung Jung\*\*

**Key Words :** Hydrogen Pressure Vessel,(수소저장용기), Liner(라이너), Butt-Fusion(열용착), Computed Tomography (컴퓨터 단층촬영)

#### ABSTRACT

The liner of Type 4 hydrogen storage vessels is manufactured by insert injection molding of polyamide 6 (PA6), a material with verified hydrogen impermeability, followed by thermal butt-fusion. In the thermal fusion process, key parameters such as heating time, temperature, and pressure, as well as preprocessing factors like the moisture content and surface roughness of hygroscopic PA6, significantly influence weld quality. This study establishes a non-destructive quality analysis process for PA6 liner welds using industrial computed tomography (CT). By comparing and analyzing weld imperfections and mechanical properties of prototype liners under varying fusion conditions, optimal process parameters were derived. This research is expected to contribute to enhancing the safety and reliability of Type 4 hydrogen storage vessels.

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## 상용차용 고압수소저장용기의 수소 충전 조건에 따른 열유동 해석

신태성\* · 박재훈\*\* · 이재철\*\*\*

### Thermal-Flow Analysis of High-Pressure Hydrogen Storage Vessels for Commercial Vehicles under Refueling Conditions

Tae-Sung Shin\*, Jae-Hun Park\*\*, Jae-Chul Lee\*\*\*

**Key Words :** Hydrogen storage vessel(수소저장용기), Hydrogen refueling(수소 충전), Computational fluid dynamics(전산유체역학), Thermal-flow analysis(열유동 해석), Thermal safety(열적 안전성)

#### ABSTRACT

Hydrogen fuel cell vehicles (FCEVs) generate electricity through the electrochemical reaction between hydrogen and oxygen to drive electric motors and are recognized as zero-emission vehicles. The hydrogen storage vessels used in commercial FCEVs typically store hydrogen gas at a high pressure of 350 or 700 bar, and the amount of stored hydrogen determines the driving range. During refueling, the gas temperature increases as the pressure rises. According to the SAE J2601 protocol, the liner temperature of the hydrogen storage vessel must not exceed 85 °C, making the study of internal temperature variation in high-pressure hydrogen storage vessels essential for ensuring safety during refueling.

In this study, computational fluid dynamics (CFD) simulations were conducted to predict the internal temperature behavior of high-pressure hydrogen storage vessels for commercial vehicles during hydrogen refueling. The analysis considered vessel installation orientation (vertical and horizontal), injection direction, and the presence or absence of a nozzle. The results showed that the internal temperature distribution varied depending on the initial refueling pressure, injection direction, and nozzle configuration. At the early stage of refueling, temperature increased uniformly throughout the vessel. However, when the injection direction was not aligned with gravity, localized hot regions appeared near the end of refueling due to density differences induced by temperature gradients and gravitational effects. When a nozzle was installed, internal flow circulation improved, and localized hot spots were effectively suppressed. This study provides a thermal-flow analysis of high-pressure hydrogen storage vessels under various refueling conditions, which is expected to contribute to thermal safety evaluation and efficiency improvement in hydrogen refueling systems.

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## 수소연료전지차량용 수소저장시스템 화재사고 안전성 검증

정해관\* · 김부근\*

### Safety Verification of Fire Accident in CHSS of Fuel Cell Electric Vehicle

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**Key Words** : Fuel Cell Electric Vehicle(수소연료전지차), Compressed Hydrogen Storage System(수소저장시스템), Fire Test(화재시험),

#### ABSTRACT

In order to implement the global carbon neutrality goal, as the development of eco-friendly FCEV technology accelerates, safety verification through advanced tests and certification is required in advanced countries including Europe. In line with these global demands, Korea's certification standards are also being revised to the same level. Existing fire test regulations for verifying the fire safety of CHSS stipulate only the size and temperature of the test burner, but recently revised regulations stipulate the shape, size and installation interval of the nozzle of the test burner as well as the amount of heat during the test. In particular, it requires pre-verification of the overall test environment using standard containers.

Through this study, we intend to develop and build a fire test system according to the revised global regulations to verify the fire safety of composite containers under development through national research projects.

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