Development of Standards for Hydrogen Storage and Transportation

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Abstract. Hydrogen storage and transportation are the intermediate link of hydrogen production and the point of end-use. Standards for hydrogen storage and transportation published by ISO, CGA, NFPA, ASME, ANSI, SAC, CEN and JISC are reviewed and analysed in this paper. Numbers of standards for hydrogen embrittlement are more than the others. Standards for hydrogen piping and pipelines are only published by CGA and ASME. Chinese GB standards are mainly focused on general design and safety, gaseous hydrogen receptacles and hydrogen embrittlement. Standards for liquid hydrogen storage receptacles and safety, hydrogen piping and pipelines, and hydrogen transportation should be emphasized.

1 Introduction

Hydrogen industry is booming in recent years under the propulsion of development of technology, climate change and energy revolution. Hydrogen can be produced from coals, natural gas, industry by-products, water, etc. The production site is always far away from the point of end-use. Hydrogen storage and transportation is the intermediate link of hydrogen production and the point of end-use. Infrastructure of hydrogen storage and transportation includes tube trailers, pipelines, and storage facilities involved in the process of delivering hydrogen, etc. [1, 2]

Hydrogen can be transported in different states, including gaseous hydrogen, liquid hydrogen and hydrogen carriers, etc. Gaseous hydrogen is the most commonly transported by tube trailers. When high volume hydrogen transportation is needed, it is often transported as the liquid. Hydrogen carriers store hydrogen in some other chemicals rather than as free hydrogen molecules, including liquid and solid hydrogen carriers.

In this paper, standards for hydrogen storage and transportation published by International Organization for Standardization (ISO), American National Standards Institute (ANSI), Compressed Gas Association (CGA), National Fire Protection Association (NFPA), American Society of Mechanical Engineers (ASME), European Committee for Standardization (CEN), State Standardization Administration of the P.R.C. (SAC), Japanese Industrial Standards Committee (JISC) are reviewed and analyzed. Suggestions of standards for hydrogen storage and transportation for China are proposed.

2 Standardization organizations

2.1 ISO

Technical Committee of Hydrogen Technologies (ISO/TC 197) is specialized in standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen [3]. Technical Committee of Surface coatings (ISO/TC 2/SC 4), Methods of testing (ISO/TC 17/SC 7), Copper and copper alloys (ISO/TC 26), Gas cylinders (ISO/TC 58), and Corrosion of metals and alloys (ISO/TC 156) are specialized in preparing standards for hydrogen embrittlement.

2.2 American organizations

American National Standards Institute (ANSI), Compressed Gas Association (CGA), National Fire Protection Association (NFPA), American Society of Mechanical Engineers (ASME) are all specialized in preparing standards for hydrogen storage and transportation [4-7].

2.3 CEN

European Committee for Standardization (CEN) is a public organization which prepares European Standards (EN standards) and other technical documents in relation to various kinds of products, materials, services and processes [8]. CEN/TC 23 (Transportable gas cylinders) covers standardization of transportable gas cylinders, their fittings, and requirements relating to their design,

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testing and operation. CEN/TC 133 (Copper and copper alloys), CEN/TC 185 (Fasteners), CEN/TC 262 (Metallic and other inorganic coatings, including for corrosion protection and corrosion testing of metals and alloys), and CEN/TC 459/SC 1 (Test methods for steel (other than chemical analysis)) are technical bodies which prepare standards for hydrogen embrittlement.

2.4 SAC

Standardization Administration of the People's Republic of China (SAC) supervises and coordinates standardization work in China. Technical Committee of Hydrogen Energy (SAC/TC 309), High Pressure Vehicle Fuel Tanks (SAC/TC 31/SC 8), Road Vehicles (SAC/TC 114), and Boilers and Pressure Vessels (SAC/TC 262) are the main technical committees which devote to develop standards for hydrogen storage and transportation. Technical Committee of Nonferrous Metals (SAC/TC 243), Metallic and Non-metallic Coatings (SAC/TC 57), Steel (SAC/TC 183) and Fasteners (SAC/TC 85) prepare standards for hydrogen embrittlement. SAC published Chinese national standards are marked as GB standards [9].

2.5 JISC

The Japanese Industrial Standards Committee (JISC), Japan's national standardization body, plays a central role in developing standards in Japan covering a wide range of products and technologies [10]. JISC published standards are marked as JIS standards .

3 Standards for hydrogen storage and transportation

As is shown in Figure 1, standards for hydrogen storage and transportation include general design and safety, receptacles, piping and pipelines, hydrogen embrittlement, etc.

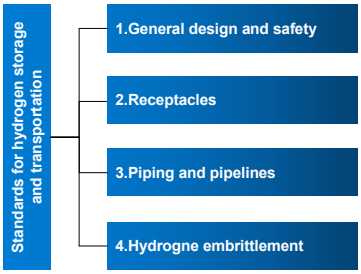

Fig. 1. Framework of Standards for Hydrogen Storage and Transportation

3.1 General design and safety

As is listed in Table 1, there are 14 standards for general design and safety, including 8 CGA standards, 2 NFPA standards and 4 GB standards. CGA standards cover the installation, handling, safety and set of hydrogen storage and supply systems. NFPA 2 covers fundamental requirements of storage and piping of compressed gaseous hydrogen and cryogenic liquid hydrogen. NPFA 55 covers the storage requirements of compressed gases and cryogenic hydrogen in portable and stationary containers, cylinders and tanks. GB standards provide safety requirements for hydrogen transportation, hydrogen storage devices and systems.

Table 1. General design and safety standards for hydrogen storage and transportation[5,6,9]

No.	Number of standards	Name of standards
1	CGA H-5-2014	Installation standard for bulk hydrogen supply systems
2	CGA P-12-2017	Safe handling of cryogenic liquids
3	CGA PS-17-2004	CGA position statement on underground installation of liquid hydrogen storage tanks
4	CGA PS-20	CGA Position statement on the direct burial of gaseous hydrogen storage tanks
5	CGA P-28-2014	Risk management plan guidance document for bulk liquid hydrogen systems
6	CGA P-41-2018	Locating bulk liquid storage systems in courts
7	CGA PS-46-2017	Position statement - roofs over hydrogen storage systems
8	CGA PS-48-2016	CGA Position statement on clarification of existing hydrogen setback distances and development of new hydrogen setback distances in NFPA 55
9	NFPA 2	Hydrogen technologies code
10	NFPA 55	Compressed gases and cryogenic fluids code
11	GB/T 34583-2017	Safety technical requirements for hydrogen storage devices used in hydrogen fuelling station
12	GB/T 34584-2017	Safety technical regulations for hydrogen refueling station
13	GB/T 29729-2013	Essential requirements for the safety of hydrogen systems
14	GB/T 34542.1-2017	Storage and transportation systems for gaseous hydrogen-Part 1: General requirements

3.2 Receptacles

Hydrogen receptacles include cylinders, tanks, storage devices, containers, storage buffers, etc. As is shown in Table 2, Table 3 and Table 4, there are 22 standards for hydrogen receptacles.
Table 2 shows standards for stationary and transportable receptacles, including 1 ISO standard, 2 GB standards, 2 CGA standards and 2 EN standards. ISO 16111:2018 and GB/T 33292-2016 are standards for metal hydride hydrogen storage devices and systems. GB/T 26466-2011, EN 17533: 2020, EN 17339: 2020 and CGA PS-33-2008 (R2014) are standards for gas hydrogen stationary storage.

CGA H-3-2019 is the standard for cryogenic hydrogen Storage.

Table 2. Standards for stationary and transportable hydrogen storage receptacles[3,5,8,9]

No.	Number of standards	Name of standards
1	ISO 16111:2018	Transportable gas storage devices - Hydrogen absorbed in reversible metal hydride
2	GB/T 26466-2011	Stationary flat steel ribbon wound vessels for storage of high pressure hydrogen
3	GB/T 33292-2016	Metal hydride hydrogen storage system for fuel cells backup power
4	CGA H-3-2019	Standard for cryogenic Hydrogen Storage
5	CGA PS-33-2008 (R2014)	Use of liquefied petroleum gas or propane tanks as compressed hydrogen storage buffers
6	EN 17533: 2020	Gaseous hydrogen - Cylinders and tubes for stationary storage
7	EN 17339: 2020	Transportable gas cylinders - Fully wrapped carbon composite cylinders and tubes for hydrogen

Table 3 shows standards for hydrogen receptacles of fuel cell vehicles, including 3 ISO standards, 4 GB standards and 2 ANSI standards. ISO 13985:2006 specifies the requirements of liquid hydrogen storage tanks on land vehicles. ISO 19881:2018, GB/T 34544-2017, GB/T 29126-2012, GB/T 26990-2011, GB/T 35544-2017 and ANSI HGV 2-2014 are for gaseous hydrogen land vehicle fuel containers and systems. ISO 19882:2018 and ANSI/CSA HPRD1-2013 are standard for thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers.

Table 3. Standards for hydrogen receptacles of fuel cell vehicles[3,4,9]

No.	Number of standards	Name of standards
1	ISO 13985:2006	Liquid hydrogen - Land vehicle fuel tanks
2	ISO 19881:2018	Gaseous hydrogen - Land vehicle fuel containers
3	ISO 19882:2018	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
4	GB/T 34544-2017	Safety test methods for onboard low pressure hydrogen storage devices for small fuel cell vehicles
5	GB/T 29126-2012	Fuel cell electric vehicles - Onboard hydrogen system - Test methods
6	GB/T 26990-2011	Fuel cell electric vehicles - Onboard hydrogen system - Specifications
7	GB/T 35544-2017	Fully-wrapped carbon fiber reinforced cylinders with an aluminum liner for the on-board storage of compressed hydrogen as a fuel for land vehicles
8	ANSI/CSA HPRD1-2013	Standard for thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
9	ANSI HGV 2-2014	Compressed hydrogen gas vehicle fuel containers

Table 4 shows standards for hydrogen storage materials, including 1 GB standard and 5 JIS standards. GB and JIS standards are all for hydrogen absorbing materials.

Table 4. Standards for hydrogen storage materials[9,10]

No.	Number of standards	Name of standards
1	GB/T 33291-2016	Measurement method of pressure-composition-temperature for reversible hydrogen absorption & desorption of hydrides
2	JIS H 7003:2007	Glossary of terms used in hydrogen absorbing alloys
3	JIS H 7201:2007	Method for measurement of pressure-composition-temperature(PCT) relations of hydrogen absorbing alloys
4	JIS H 7202:2007	Method for measurement of hydrogen absorption/desorption reaction rate of hydrogen absorbing alloys
5	JIS H 7203:2007	Method for measurement of hydrogen absorption/desorption cycle characteristic of hydrogen absorbing alloys
6	JIS H 7204:1995	Method for measuring the heat of hydrating reaction of hydrogen absorbing alloys

3.3 Piping and pipelines

Standards for hydrogen piping and pipelines are shown in Table 5, including 3 CGA standards and 2 ASME standards.

Table 5. Standards for hydrogen piping and pipelines[5,7]

No.	Number of standards	Name of standards
1	CGA G-5.4-2019	Standard for hydrogen piping systems at user locations
2	CGA G-5.6-2005	Hydrogen pipeline systems
3	CGA G-5.8-2007	High pressure hydrogen piping systems at consumer locations
4	ASME B31.12-2019	Hydrogen piping and pipelines
5	ASME STP-PT-006-2017	Design guidelines for hydrogen piping and pipelines

3.4 Hydrogen embrittlement

Hydrogen embrittlement standards are shown in Table 6, including 9 ISO standards, 9 GB standards, 1 ANSI standard, 8 EN standards and 2 JIS standards. ISO 9587:2007, ISO 9588:2007, GB/T 13322-1991, GB/T 19349-2012 and GB/T 19350-2012 are standards for hydrogen embrittlement protection. The other standards for hydrogen embrittlement testing.

Table 6. Standards for hydrogen embrittlement[3,4,8-10]

No.	Number of standards	Name of standards
1	ISO 2626:1973	Copper - Hydrogen embrittlement test
2	ISO/TR 20491:2019	Fasteners - Fundamentals of hydrogen embrittlement in steel fasteners
3	ISO 15330:1999	Fasteners - Preloading test for the detection of hydrogen embrittlement - parallel bearing surface method
4	ISO 16573:2015	Steel - Measurement method for the evaluation of hydrogen embrittlement resistance of high strength steels
5	ISO 9587:2007	Metallic and other inorganic coatings - Pretreatment of iron or steel to reduce the risk of hydrogen embrittlement
6	ISO 9588:2007	Metallic and other inorganic coatings - Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement
7	ISO 7539-11:2013	Corrosion of metals and alloys - Stress corrosion testing - Part 11: Guidelines for testing the resistance of metals and alloys to hydrogen embrittlement and hydrogen-assisted cracking
8	ISO 10587:2000	Metallic and other inorganic coatings - Test for residual embrittlement in both metallic-coated and uncoated externally-threaded articles and rods - Inclined wedge method
9	ISO 11114-4:2017	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement
10	GB/T 34542.2-2018	Storage and transportation systems for gaseous hydrogen-Part 2: Test methods for evaluating metallic material compatibility in hydrogen atmosphere
11	GB/T 34542.3-2018	Storage and transportation systems for gaseous hydrogen-Part 3: Test method for determination of the susceptibility of metallic materials to hydrogen gas embrittlement (HGE)
12	GB/T 23606-2009	Copper-hydrogen embrittlement test method(MOD：ISO 2626:1973)
13	GB/T 13322-1991	Metallic coating--Cd-Ti plating of low hydrogen embrittlement
14	GB/T 19349-2012	Metallic and other inorganic coatings - Pretreatment of iron or steel to reduce the risk of hydrogen embrittlement(IDT ISO 9587:1999)
15	GB/T 19350-2012	Metallic and other inorganic coatings - Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement(IDT ISO 9588:2007)
16	GB/T 26107-2010	Metallic and other inorganic coatings - Test for residual embrittlement in both metallic-coated and uncoated externally-threaded articles and rods - Inclined wedge method(IDT ISO 10587:2000)
17	GB/T 24185-2009	Test method for measurement of hydrogen embrittlement threshold in steel by the incremental step loading method
18	GB/T 3098.17-2000	Mechanical properties of fasteners--Preloading test for the detection of hydrogen embrittlement--Parallel bearing surface method(IDT: ISO 15330:1999)
19	ANSI/NACE TM0284-2016	Evaluation of pipeline and pressure vessel steels for resistance to hydrogen-Induced cracking
20	EN ISO 2626: 1995	Copper - Hydrogen embrittlement test
21	EN 2831: 1993	Aerospace Series - Hydrogen Embrittlement of Steels - Test by Slow Bending
22	EN 2832: 1993	Aerospace Series - Hydrogen Embrittlement of Steels - Notched Specimen Test
23	EN ISO 7539-11: 2014	Corrosion of metals and alloys - Stress corrosion cracking - Part 11: Guidelines for testing the resistance of metals and alloys to hydrogen embrittlement and hydrogen-assisted cracking
24	EN 10229: 1998	Evaluation of Resistance of Steel Products to Hydrogen Induced Cracking (HIC)
25	EN ISO 11114-4: 2017	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement
26	EN ISO 15330: 1999	Fasteners - Preloading test for the detection of hydrogen

		embrittlement - Parallel bearing surface method
27	EN ISO 17081: 2014	Method of measurement of hydrogen permeation and determination of hydrogen uptake and transport in metals by an electrochemical technique
28	JIS B 1045:2001	Fasteners - Preloading test for the detection of hydrogen embrittlement − Parallel bearing surface method
29	JIS Z 3118:2007	Method for measurement of amount of hydrogen evolved from steel welds

3.5 Distribution of standards for hydrogen storage and transportation

As is shown in Figure 2, numbers of standards for hydrogen storage and transportation published by American organizations and SAC are both 20. Numbers of standards for hydrogen storage and transportation published by ISO, CEN and JISC are separately 13, 10 and 7. American standards, including CGA, NFPA, ASME, ANSI standards, cover general design and safety, receptacles, piping and pipelines, and hydrogen embrittlement. GB standards include general design and safety, receptacles, hydrogen embrittlement, but lacking of standards for hydrogen piping and pipelines. While, ISO, EN and JIS standards cover receptacles and hydrogen embrittlement.

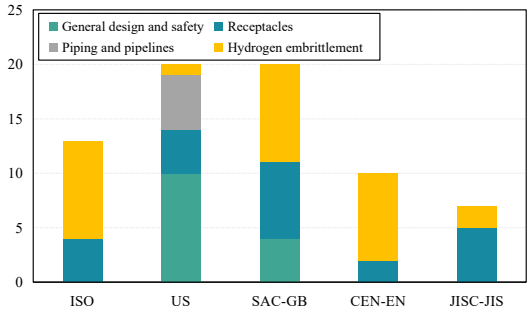

Fig. 2. Numbers of Standards for Hydrogen Storage and Transportation Published by Different Organizations and Countries

As is shown in Figure 3, numbers of standards for hydrogen embrittlement are more than that of the others, which accounts for about 40%. Numbers of standards for general design and safety, receptacles, and piping and pipelines account for 20%, 32% and 7% separately. Standards for hydrogen piping and pipelines should be emphasized.

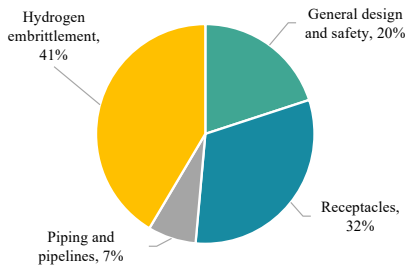

Fig. 3. Distribution of Standards for Hydrogen Storage and Transportation Based on Standard Types

4 Conclusions

Hydrogen storage and transportation are the intermediate link of hydrogen production and the point of end-use. Standards for hydrogen storage and transportation published by ISO, CGA, NFPA, ASME, ANSI, SAC, CEN and JISC cover general design and safety, receptacles, piping and pipelines, hydrogen embrittlement, etc. Numbers of standards for hydrogen embrittlement are more than the others. Standards for hydrogen piping and pipelines are only published by CGA and ASME. Chinese GB standards are mainly focused on general design and safety, gaseous hydrogen receptacles and hydrogen embrittlement. Standards for liquid hydrogen storage receptacles and safety, hydrogen piping and pipelines, and hydrogen transportation should be emphasized.

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