Comparison Study of Material Storage Tank of Compressed Hydrogen Fuel Cell Electric Vehicle (FCEV)

Wigas Digwijaya
PLN Research Institute Jl. Duren Tiga Raya No.102, RT.8/RW.1, Duren Tiga, Pancoran

Handrea Bernando Tambunan
PLN Research Institute Jl. Duren Tiga Raya No.102, RT.8/RW.1, Duren Tiga, Pancoran

Sulistyo
University of Diponegoro, Jl. Prof. Soedharto, SH. Tembalang

Tutuk Djoko Kusworo
University of Diponegoro, Jl. Prof. Soedharto, SH. Tembalang

他

https://doi.org/10.5109/7327000

出版情報：Evergreen. 11 (4), pp.3693-3699, 2024-12. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Comparison Study of Material Storage Tank of Compressed Hydrogen Fuel Cell Electric Vehicle (FCEV)

Wigas Digwijaya[1], Handrea Bernando Tambunan[1], Sulistyo[2,*], Tutuk Djoko Kusworo[2], Muchammad[2]

[1]PLN Research Institute Jl. Duren Tiga Raya No.102, RT.8/RW.1, Duren Tiga, Pancoran, Jakarta Selatan, DKI Jakarta 12760, Indonesia

[2]University of Diponegoro, Jl. Prof. Soedharto, SH. Tembalang, Semarang 59275, Indonesia

*Author to whom correspondence should be addressed:
E-mail: sulistyo@lecturer.undip.ac.id

(Received May 17, 2024; Revised August 22, 2024; Accepted December 17, 2024).

Abstract: Currently the problem of greenhouse effect is into the world spotlight due to CO_2 emissions. Sources of CO_2 gas production in large cities from the transportation sector have reached around 60 - 70%. Efforts to reduce CO_2 gas production are carried out by developing environmentally friendly vehicles, including battery-based electric vehicles (BEV) or fuel cell electric vehicles (FCEV). FCEV is expected to be an environmentally friendly vehicle whose technology is mature. The main components of FCEV system consists of fuel cell stack that converts hydrogen gas into electricity, gas supply, wheel drive motor and hydrogen gas storage tank. The purpose of this article is to discuss a comparison of hydrogen gas storage tank materials from Aluminum (Al), Fiber glass composite and Stainless steel (SS) which have a working pressure 87.5 MPa (875 bar) by comparing the thickness of the tank wall, safety factor, and tank mass. The study carried out the analysis of strength of using ASME CODE pressure vessel of tanks from various materials. The shape of the hydrogen gas storage tank is a cylinder with a capacity of 5.6 kg with a volume of 142.2 L. The material of storage tank is aluminium (Al), fiber glass and stainless steel (SS). Each material was evaluated the strength, thickness and mass of storage tank. The yield stress materials was taken from secondary data to evaluate the safety factor material. The result analysis of storage tank material shown that the lightest mass is fiber glass of 92.3 kg while stainless steel the heaviest of 1381.33 kg. The thinnest of material with safety factor of 1 is fiber glass material.

Keywords: FCEV; ASME CODE; strength materials; safety factor; storage tank

1. Introduction

The development of vehicles is currently very rapid. The increasing number of vehicles is influenced by the level of economic income which is quite good[1)]. The increase in the number of combustion motor vehicles has an impact on the production of CO_2 gas in the air which continues increase[2)]. On the European continent, the transportation sector produced CO_2 gas emissions from 1990 of 0.79 Gt and increased to 0.95 Gt in 2017[3)]. The largest increase in CO_2 gas was from the transportation sector[4)]. The increase in the amount of CO_2 gas has an impact on the greenhouse effect[5)]. Efforts to reduce the greenhouse effect continue to be made by developing renewable energy[6)]. Currently, the energy system is facing many challenges mainly stem from climate change and decarbonization policies, while the use of hydrogen gas seems to be able to overcome some of these problems[7)]. The transition from fossil fuels to low or zero carbon energy sources is a key goal of almost all global energy policies and strategies[8)]. However, generating units based on low or zero carbon energy sources often experience problems when dispatched to conventional thermal power plants fueled by coal or natural gas[9)].

To reduce CO_2 and other greenhouse gas emissions, governments in most developed countries are promoting the use of electric vehicles[10)]. There are four types of electric cars that has been sold in the worldwide that is pure electric cars, fuel cell cars, hybrid electric cars, and plug-in hybrid cars[11)]. The pure electric cars maybe the electric power source are still from carbon burning. Fuel cell car is pure green atmosphere due to fuel cell use the pure hydrogen gas[12)]. This condition is better in the human activity[13)]. Zero-emission vehicles are usually electric vehicles that have no tailpipe emissions, such as battery-based electric vehicles (BEVs) or fuel cell electric vehicles (FCEVs)[14)]. Thus BEVs and FCEVs will create the green environment that can be to reduce emission CO_2[15)]. Figure 1 show the component of FCEV. The component are fuel cell stack, wire systems, wheel hub motor, lithium-ion battery, front electric motor, hydrogen storage tank[16]. Hydrogen storage tank of FCEV was built to resist inner pressure of 350 bar or 875 bar[17].

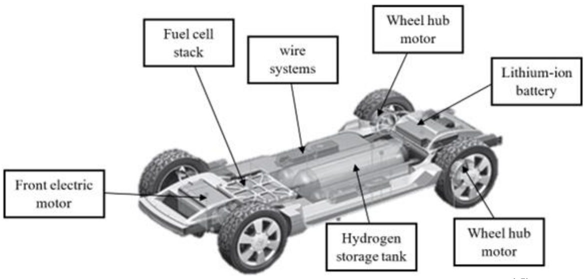

Fig. 1: Component of Fuel Cell Electric Vehicle[15].

The mass of the storage tank is important on FCEVs[18]. This storage tank must be able to accommodate hydrogen gas over a certain distance, like existing vehicles. With long distances, great pressure is required to accommodate hydrogen energy which is equivalent to fossil energy. The standard 4 passenger light vehicle used is a tank pressure of 87.5 MPa and a gas mass of 5.6 kg[17]. Based on the working pressure of hydrogen gas, an analysis of the strength of materials suitable for use as tanks in FCEV is carried out[19]. The analysis approach uses equations that have been developed by the ASME code for equations 1 to 5[20]. From this analysis we can obtain sufficient information in determining tank materials[21]. There are several design of hydrogen storage tank as type of vertical storage tank, sphere storage tank and horizontal storage tank as in Fig. 2[22].

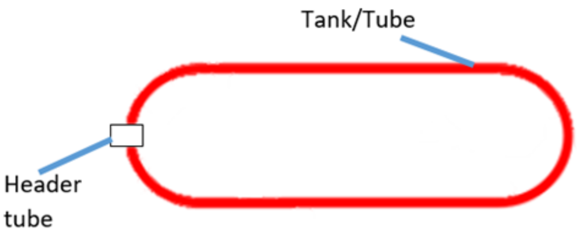

Fig. 2: Hydrogen Horizontal Storage Tank[22].

Working pressure in the storage tank will result internal stress (allowable stress) of the materials[23]. This stress should be under yield strength of the materials[24]. To know allowable stress of the materials was use by using of design pressure vessel based on ASME Code[21].

There are several material choices that can be used as hydrogen gas storage tanks. The materials compared are aluminum material, stainless steel material and glass fiber composite material.

This third material was chosen as a comparison in terms of strength and tank wall thickness as well as resistance to environmental corrosion. Aluminum (Al) and stainless steel (SS) are metal materials that are good against corrosion attacks in open air environments. Glass fiber is a composite material (Glass Fiber Reinforced Plastic/FGRP) which has a lower density than the two metal materials Aluminum and SS. The advantage of FGRP is that it has better tensile strength compared to Al and SS materials. Thus, it is suitable as a hydrogen gas storage material in vehicles.

2. Method

The selection of thickness pressure vessel can be analysed by formula which was written on (1) until (6). Analysis was helped by excel software which available on the computer. The step of solution can be seen by flowchart in Fig. 3. The flowchart shown the action of analysis of strength materials based on ASME Section VIII, Division 1[21].

First, working pressure and volume capacity of storage tank must be entered in the system[25]. The working pressure is 87.5 MPa[26]. Analysis of thickness pressure vessel used ASME Code pressure vessel[27]. Evaluation of the thickness materials were carried out by using excel software. Several materials was done by using same analysis. Its analysis can be given the information of thickness, mass, working stress, and safety factor[28].

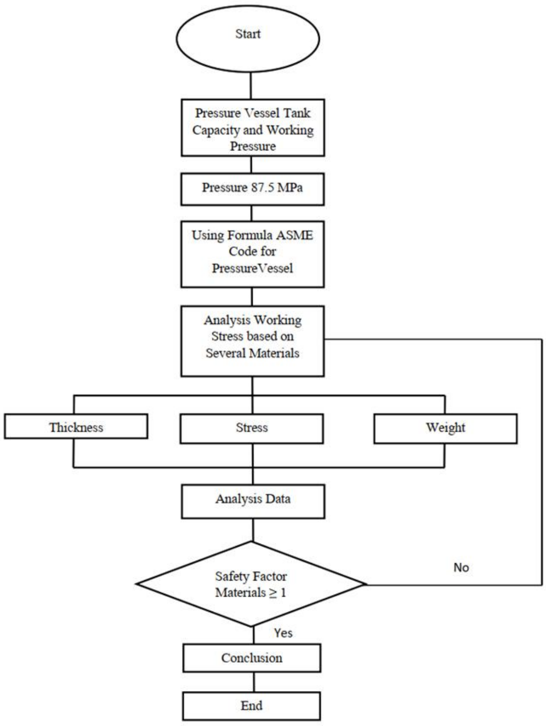

Fig. 3: Flowchart Research Activity.

From Fig. 3 it can be explained that the first step is to determine the working pressure of the tank and the volume of hydrogen gas. The inner diameter of the tank is determined according to the dimensions of the vehicle. The inside diameter of the tank is set at 400 mm. The next stage is to enter a formula based on ASME code standards and enter the material types Al, fiber glass and SS. Each material is analyzed for strength based on working pressure, thickness and safety factor. The final stage is to evaluate if the safety factor is equal to or greater than 1 then the material thickness will be obtained. From the thickness of the material, the mass of the tank is calculated[29]. The formula of thickness pressure vessel can use by using formula (1), (2), (3), and (4), while the volume by using formula (5) and (6).

Equation of Cylindrical Shell

$$t = \frac{Pr}{SE - 0{,}6P} \quad (1)$$

$$P = \frac{SEt}{r + 0{,}6t} \quad (2)$$

Equation of Sphere Hemisperical Head

$$t = \frac{Pr}{2SE - 0{,}2P} \quad (3)$$

$$P = \frac{2SEt}{r + 0{,}2t} \quad (4)$$

Equation to find Cylinder Shell Volume

$$V_{cylinder\ shell} = \pi r_o^2 l - \pi r_i^2 l \quad (5)$$

Equation to find Sphere Shell Volume

$$V_{sphere\ shell} = \frac{4}{3}\pi r_o^3 - \frac{4}{3}\pi r_i^3 \quad (6)$$

Equation to find Total Volume

$$V_{Total} = (\pi r_o^2 l - \pi r_i^2 l) + \left(\frac{4}{3}\pi r_o^3 - \frac{4}{3}\pi r_i^3\right) \quad (7)$$

Equation to find total mass of the tank

$$m_{Total} = V_{Total}\ x\ Density \quad (8)$$

Parameter for calculation of working stress storage tank can be seen in Table 1.

Table 1. Parameter for Calculation of Working Stress.

No	Parameter	Unit or Value
1.	Working Pressure	MPa
2.	Thickness	M
3.	Working Stress	MPa
4.	Inside Diameter of the Tank	0.4 m
5.	Safety Factor ($N = \sigma_y/S$)	-

3. Result and Discusion

The result of thickness calculation analysis for materials aluminium, stainless steel (SS) and fiber glass that can be seen in the Table 2, Table 3 and Table 4 below.

Table 2. Calculation for Aluminum Material (E=0.9).

t (mm)	S (MPa)	N
40	544.44	0.63
42	521.30	0.66
44	500.25	0.69
46	481.04	0.72
48	463.43	0.74
50	447.22	0.77
52	432.26	0.80
54	418.42	0.82
56	405.56	0.85
58	393.58	0.88
60	382.41	0.90
62	371.95	0.93
64	362.15	0.95
66	352.95	0.98
68	344.28	1.00
70	336.11	1.03
72	328.40	1.05
74	321.10	1.07
76	314.18	1.10

In Table 2, it can be seen that the thickness required for aluminum material to withstand a pressure of 87.5 MPa with a value (E = 0.9) is 68 mm. The value E = 0.9 was taken because it is assumed that the tank has connections and valve. The safety factor on aluminum with thickness of 68 mm is 1.0[21]. Yield strength of material Al is 345 MPa[22]. From Table 2 shown the thickness of 40 mm, the working stress of storage tank is 544.44 MPa and the safety factor is 0.63. At thickness of 68 mm, the working stress is 344.28 MPa with safety factor is 1.00.

The value 1.00-1.01 is the minimum value for the factor of safety (FoS) which is calculated from the ratio between the yield strength of the material (MPa) and the maximum allowable working stress value (MPa). FoS value is 1.00-1.01: Indicates that the allowable stress acts in the elastic area so that the construction is safe for use at a pressure of 87.5MPa. FoS less than 1.00: Indicates that the material thickness and strength are inadequate to withstand the maximum allowable working stress. The working area at FoS less than 1 is a plastic area so it is not permitted because plastic deformation will occur which will damage the tank structure. FoS more than 1.00: Indicates that the material thickness and strength are greater than required to withstand the maximum working stress. This design is safe, but inefficient and wasteful in terms of material use and tank mass.

Table 3. Calculation for Stainless Steel (SS) Material (E=0.9).

t (mm)	S (MPa)	N
56	405.56	0.71507
58	393.58	0.73682
60	382.41	0.75835
62	371.95	0.77967
64	362.15	0.80077
66	352.95	0.82166
68	344.28	0.84234
70	336.11	0.86281
72	328.40	0.88308
74	321.10	0.90316
76	314.18	0.92303

78	307.62	0.94272
80	301.39	0.96221
82	295.46	0.98152
84	289.81	1.00064
86	284.43	1.01958
88	279.29	1.03834
90	274.38	1.05692
92	269.69	1.07532

In Table 3, it can be seen that the thickness required for stainless steel material to withstand a pressure of 87.5 MPa with a value (E = 0.9) is 84 mm. The value E = 0.9 was taken because it is assumed that the tank has connections and valve. The safety factor on stainless steel with thickness of 84 mm is 1.0 (E = 0.9)[30]. From Table 3 shown the thickness of 56 mm, the working stress of storage tank is 405.56 MPa and the safety factor is 0.71. At thickness of 84 mm, the working stress is 289.81 MPa with safety factor is 1.00.

Table 4. Calculation for Fiber Glass Material (E=0.9).

t (mm)	S (MPa)	N
2	9,780.56	0.08
4	4,919.44	0.15
6	3,299.07	0.23
8	2,488.89	0.31
10	2,002.78	0.38
12	1,678.70	0.45
14	1,447.22	0.53
16	1,273.61	0.60
18	1,138.58	0.67
20	1,030.56	0.74
22	942.17	0.81
24	868.52	0.88
26	806.20	0.94
28	752.78	1.01
30	706.48	1.08
32	665.97	1.14
34	630.23	1.21
36	598.46	1.27
38	570.03	1.33

In Table 4, it can be seen that the thickness required for fiber glass material to withstand a pressure of 87.5 MPa with a value (E = 0.9) is 28 mm. The value E = 0.9 was taken because it is assumed that the tank has connections and valve. The safety factor on fiber glass with thickness of 28 mm is 1.01 (E = 0.9)[31]. From Table 4 shown the thickness of 22 mm, the working stress of storage tank is 942.17 MPa and the safety factor is 0.81. At thickness of 28 mm, the working stress is 752.78 MPa with safety factor is 1.01.

Table 5. Result of Material Safety Factor Calculation.

Materials	σ_y (MPa)	t (mm)	S (MPa)	N
Aluminium	345.00	68	344.28	1.00
Stainless Steel	290.00	84	289.81	1.00
Fiber Glass	760.00	28	752.78	1.01

Table 6. Comparison Mass Calculation Analysis Based On Materials.

Materials	V_w (cm^3)	ρ (g/cm^3)	m (kg)
Aluminium	133,365.39	2.78	370.76
Stainless Steel	172,665.70	8.00	1,381.33
Fiber Glass	48,641.18	2.00	97.28

Based on Table 5 and Table 6, it can be seen the mass of stainless steel material, aluminium and fiber glass are 1,381 kg, 370.76 kg and 97.28 kg respectively. The mass of tank is calculated by equation 8. The yield strength of stainless steel material is 290 MPa[30], which has specification SS 304L[32]. The lightest mass is fiber glass[33]. This condition is the basis for determining the use of fiber glass material because it will reduce the mass of the vehicle if used in the automotive industry. The analysis shown the thickness of the material due to the yield strength of the materials and the working pressure in the tank around 87.5 MPa. For application of fuel cell electric vehicles (FCEV) should be had the mass of storage tank the smallest mass due to it will increase the efficiency of fuel consumption[34].

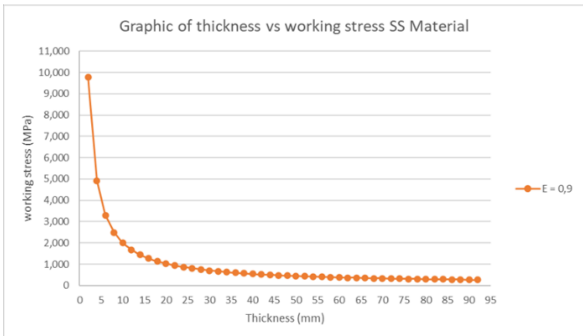

Fig. 4: Graphic of Thickness vs Working Stress SS material at Working Pressure of 87.5 MPa.

In Fig. 4 above, it can be seen the graphic relation about the thickness material and working stress of the material. The working pressure of the tank is 87,5 MPa. The increase of the wall thickness of storage tank will reduce the working stress[21]. The thickness of storage tank will affect the mass of tank. In general, the thickness of the material can affect the stress distribution in the material. Therefore the more thick of material the stress distribution tends to be more evenly so that the working stress that occurs is smaller[35].

4. Conclusion

Analysis storage tank of compressed hydrogen have be done by using ASME Code, (ASME Section VIII, Division 1). The working stress was affected by thickness of tank wall. Increasing of the thickness will reduce of the working stress but it will increase the mass of tank.

The value 1.00-1.01 is the minimum value for the factor of safety (FoS) which is calculated from the ratio between the yield strength of the material (MPa) and the maximum allowable working stress value (MPa). FoS value is 1.00-1.01: Indicates that the allowable stress acts in the elastic area so that the construction is safe for use at a pressure of 87.5MPa.

Result of mass analysis of storage tank based on working pressure of 87.5 MPa for aluminium, stainless steel and fiber glass are 370.76 kg, 1,381.33 kg and 97.28 kg respectively. The lightest mass of storage tank is fiber glass material. It can be used as reference of selection materials for hydrogen storage tank of fuel cell electric vehicles (FCEV).

Acknowledgements

Authors has to thank you to the parties who have supported the smooth implementation of the research. The relevant parties who have supported the smooth running of this research are PLN Research Institute that have collaborated with University of Diponegoro.

Nomenclature

S	maximum allowable working stress value (MPa)
t	thickness, excluding corrosion allowance (m)
P	maximum allowable working pressure (MPa)
r	radius excluding corrosion allowance (m)
r_i	inside radius excluding corrosion allowance (m)
r_o	outside radius excluding corrosion allowance (m)
π	pi (-)
d	inside diameter excluding corrosion allowance (m)
l	length of cylinder (m)
E	joint efficiency (-)
σ_y	yield strength material (MPa)
N	safety factor (-)
V_w	total volume of wall (cm^3)
ρ	mass density (g/cm^3)
m	mass (kg)

References

1) J. Zou, N. Han, J. Yan, Q. Feng, Y. Wang, Z. Zhao, J. Fan, L. Zeng, H. Li, and H. Wang, "Electrochemical Compression Technologies for High-Pressure Hydrogen: Current Status, Challenges and Perspective," Springer Singapore, (2020). doi:10.1007/s41918-020-00077-0.
2) M.A. Aminudin, S.K. Kamarudin, B.H. Lim, E.H. Majilan, M.S. Masdar, and N. Shaari, "An overview: current progress on hydrogen fuel cell vehicles," *Int. J. Hydrogen Energy*, **48** (*11*) 4371–4388 (2023). doi:10.1016/j.ijhydene.2022.10.156.
3) C. Wang, J. Wood, X. Geng, Y. Wang, C. Qiao, and X. Long, "Transportation co2 emission decoupling: empirical evidence from countries along the belt and road," *J. Clean. Prod.*, **263** 121450 (2020). doi:10.1016/j.jclepro.2020.121450.
4) S. Jain, and S. Rankavat, "Analysing driving factors of india's transportation sector co2 emissions: based on lmdi decomposition method," *Heliyon*, **9** (*9*) e19871 (2023). doi:10.1016/j.heliyon.2023.e19871.
5) D. Apostolou, "Refuelling scenarios of a light urban fuel cell vehicle with metal hydride hydrogen storage. comparison with compressed hydrogen storage counterpart," *Int. J. Hydrogen Energy*, **46** (*79*) 39509–39522 (2021).
6) M.A. Lima, L.F.R. Mendes, G.A. Mothé, F.G. Linhares, M.P.P. de Castro, M.G. da Silva, and M.S. Sthel, "Renewable energy in reducing greenhouse gas emissions: reaching the goals of the paris agreement in brazil," *Environ. Dev.*, **33** (*February 2020*) 100504 (2020). doi:10.1016/j.envdev.2020.100504.
7) D.L. Greene, J.M. Ogden, and Z. Lin, "Challenges in the designing, planning and deployment of hydrogen refueling infrastructure for fuel cell electric vehicles," *ETransportation*, **6** 100086 (2020). doi:10.1016/j.etran.2020.100086.
8) R. Murphy, "What is undermining climate change mitigation? how fossil-fuelled practices challenge low-carbon transitions," *Energy Res. Soc. Sci.*, **108** (*December 2023*) 103390 (2024). doi:10.1016/j.erss.2023.103390.
9) A. Komorowska, P. Olczak, and E. Hanc, "ScienceDirect an analysis of the competitiveness of hydrogen storage and li-ion batteries based on price arbitrage in the day-ahead market ski," **7** (2022). doi:10.1016/j.ijhydene.2022.06.160.
10) S. Abdul Qadir, F. Ahmad, A. Mohsin A B Al-Wahedi, A. Iqbal, and A. Ali, "Navigating the complex realities of electric vehicle adoption: a comprehensive study of government strategies, policies, and incentives," *Energy Strateg. Rev.*, **53** (*February*) 101379 (2024). doi:10.1016/j.esr.2024.101379.
11) D. Alcázar-García, and J.L. Romeral Martínez, "Model-based design validation and optimization of drive systems in electric, hybrid, plug-in hybrid and fuel cell vehicles," *Energy*, **254** (2022). doi:10.1016/j.energy.2022.123719.
12) T. Hai, M.A. Ali, F.M. Zeki, B.S. Chauhan, A.S. Mohammed Metwally, and M. Ullah, "Optimal design of inter-state hydrogen fuel cell vehicle fueling station with on-site hydrogen production," *Int. J. Hydrogen Energy*, **52** 733–745 (2024). doi:10.1016/j.ijhydene.2023.03.274.
13) R. Van der Borght, and M. Pallares Barbera, "How

urban spatial expansion influences co2 emissions in latin american countries," *Cities*, **139** (*November 2022*) 104389 (2023). doi:10.1016/j.cities.2023.104389.
14) S. Vengatesan, A. Jayakumar, and K.K. Sadasivuni, "FCEV vs. bev — a short overview on identifying the key contributors to affordable & clean energy (sdg-7)," *Energy Strateg. Rev.*, **53** (*March*) 101380 (2024). doi:10.1016/j.esr.2024.101380.
15) M. Waseem, M. Amir, G.S. Lakshmi, S. Harivardhagini, and M. Ahmad, "Fuel cell-based hybrid electric vehicles: an integrated review of current status, key challenges, recommended policies, and future prospects," *Green Energy Intell. Transp.*, **2** (*6*) 100121 (2023). doi:10.1016/j.geits.2023.100121.
16) A.K. Nayak, B. Ganguli, and P.M. Ajayan, "Advances in electric two-wheeler technologies," *Energy Reports*, **9** 3508–3530 (2023). doi:10.1016/j.egyr.2023.02.008.
17) T.Q. Hua, R.K. Ahluwalia, J.K. Peng, M. Kromer, S. Lasher, K. McKenney, K. Law, and J. Sinha, "Technical assessment of compressed hydrogen storage tank systems for automotive applications," *Int. J. Hydrogen Energy*, **36** (*4*) 3037–3049 (2011). doi:10.1016/j.ijhydene.2010.11.090.
18) Q. Cheng, R. Zhang, Z. Shi, and J. Lin, "Review of common hydrogen storage tanks and current manufacturing methods for aluminium alloy tank liners," *Int. J. Light. Mater. Manuf.*, **7** (*2*) 269–284 (2024). doi:10.1016/j.ijlmm.2023.08.002.
19) B. Bijeta Nayak, H. Jena, D. Dey, B. Kassaye Oda, A. Chetia, S. Kumar Brahma, T. Bordoloi, and D. Chakraborty, "Materials selection and design analysis of cryogenic pressure vessel: a review," *Mater. Today Proc.*, **47** 6605–6608 (2020). doi:10.1016/j.matpr.2021.05.095.
20) R. Sharma, and A. Pachauri, "A review of pressure vessels regarding their design, manufacturing, testing, materials, and inspection," *Mater. Today Proc.*, (*xxxx*) (2023). doi:10.1016/j.matpr.2023.03.258.
21) K. Hazizi, and M. Ghaleeh, "Design and analysis of a typical vertical pressure vessel using asme code and fea technique," *Designs*, **7** (*3*) (2023). doi:10.3390/designs7030078.
22) Q. Cheng, R. Zhang, Z. Shi, and J. Lin, "Review of common hydrogen storage tanks and current manufacturing methods for aluminium alloy tank liners," *Int. J. Light. Mater. Manuf.*, (2023). doi:10.1016/j.ijlmm.2023.08.002.
23) C. Wang, S. Huang, and S. Xu, "Optimization of girth welded joint in a high-pressure hydrogen storage tank based on residual stress considerations," *Int. J. Hydrogen Energy*, **43** (*33*) 16154–16168 (2018). doi:10.1016/j.ijhydene.2018.07.011.
24) M.A. Assegie, O. Siram, P. Kalita, and N. Sahoo, "Novel small-scale spring actuated scissor-jack assembled isobaric compressed air energy storage tank: design analysis and simulation," *J. Energy Storage*, **89** (*October 2023*) 111627 (2024). doi:10.1016/j.est.2024.111627.
25) Sofoklis Makridis, "Hydrogen storage and compression," *Chem. Phys.*, (2017). doi:10.1049/PBPO101E_ch1.
26) Y. Su, H. Lv, C. Feng, and C. Zhang, "Hydrogen permeability of polyamide 6 as the liner material of type iv hydrogen storage tanks: a molecular dynamics investigation," *Int. J. Hydrogen Energy*, **50** (*PD*) 1598–1606 (2024). doi:10.1016/j.ijhydene.2023.10.154.
27) G. Drumond, R. Ribeiro, I. Pasqualino, M.I. Souza, V. Perrut, and L.D. Lana, "Analysis of the efficiency of corroded pressure vessels with composite repair – part ii," *Int. J. Press. Vessel. Pip.*, **206** (*July*) 105042 (2023). doi:10.1016/j.ijpvp.2023.105042.
28) J.H. Fu, K.P. Zhu, J.G. Gong, F.H. Gao, and F.Z. Xuan, "Correlation between reliability and safety factor based methods in characterizing uncertainty of creep rupture properties," *Int. J. Press. Vessel. Pip.*, **206** (*October*) 105068 (2023). doi:10.1016/j.ijpvp.2023.105068.
29) D. Prajapati, and R. Trivedi, "Design of flash vessel for caustic recovery plant," *Mater. Today Proc.*, (*xxxx*) (2023). doi:10.1016/j.matpr.2023.03.008.
30) B. Leffler, "Stainless-stainless steels and their properties," *Outokumpu Oy n Sivuilta*, (1998).
31) S. Mohammad Shohel, S. Hossain Riyad, and A. All Noman, "Study to analyze the mechanical strength of composite glass fiber laminated with resin epoxy, resin polyester, and pvc foam under tensile loading conditions by numerically using finite element analysis via ansys," *Mater. Today Proc.*, (*xxxx*) (2023). doi:10.1016/j.matpr.2023.05.062.
32) K. Mohta, S.K. Gupta, S. Cathirvolu, S. Jaganathan, and J. Chattopadhyay, "High temperature deformation behavior of indian phwr calandria material ss 304l," *Nucl. Eng. Des.*, **368** (*September*) 110801 (2020). doi:10.1016/j.nucengdes.2020.110801.
33) J. Xue, R. Han, Y. Ge, L. Liu, and Y. Yang, "Preparation, mechanical, acoustic and thermal properties of silica composite aerogel using wet-laid glass fiber felt as scaffold," *Compos. Part A Appl. Sci. Manuf.*, **179** (*September 2023*) 108058 (2024). doi:10.1016/j.compositesa.2024.108058.
34) M. Ahmadifar, K. Benfriha, M. Shirinbayan, A. Aoussat, and J. Fitoussi, "Exploring fatigue characteristics of metallic boss-polymer liner adhesion in hydrogen storage tanks: experimental insights post surface treatment," *J. Energy Storage*, **75** (*November 2023*) 109771 (2024). doi:10.1016/j.est.2023.109771.
35) J. Ning, C. Deng, Y. Wang, B. Gong, B. Guo, C. Wang, N. Zhao, and L. Dai, "Stress state analysis of

root notch for x80 girth welds with variable wall thickness and misalignment geometric features," *Int. J. Press. Vessel. Pip.*, **206** (*October*) 105064 (2023). doi:10.1016/j.ijpvp.2023.105064.