Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(8) (2022) 379-382
DOI: 10.22060/mej.2022.20911.7335

Simulation and Analysis of the First to Fourth Types of Compressed Natural Gas Tanks of Vehicles under the Explosive Loading

A. Albooyeh [1*], S. Amirabdollahian [2], N. Fatahi [1]

[1] Department of Engineering, Damghan University, Damghan, Iran
[2] Department of Mechanical and Mechatronics Engineering, Shahrood University of Technology, Shahroud, Iran

ABSTRACT: In the current research, the behavior of the first to fourth types of compressed natural gas tanks of the vehicle under internal pressure and the external explosive load was investigated in the ABAQUS finite element software. At first, the hydrostatic pressure of about 200 bar was applied to ensure that these tanks do not fail under internal pressure, and the failure index of these tanks was evaluated using the Tsai-Hill criterion. Then, the CONWEP model was used to investigate the behavior of tanks under external explosive load. For this purpose, Trinitrotoluene material was applied in two explosion points (near and far) and three different explosion charge values. In the explosion simulation, the amount of damage to the metal and composite parts of the tanks was evaluated using the Johnson-Cook and Hashin criteria, respectively. The results of this research show that the fourth type of tank has the highest strength against internal hydrostatic pressure compared to other tanks and can withstand up to 610 bar pressure. In addition, the third type of tank has the highest safety against external explosion waves. A comparison of the results related to the second to fourth type composite tanks shows that the presence of steel liner under the composite layer has a significant effect on the strength of the tank against impact or explosion. Another important result obtained is that the first type of tank despite the high weight has good resistance to internal pressure as well as an explosive wave.

Review History:

Received: Dec. 23, 2021
Revised: May, 15, 2022
Accepted: Jul. 03, 2022
Available Online: Aug. 08, 2022

Keywords:

Compressed natural gas tanks
Composite tanks
Explosion
Johnson-Cook failure criterion
Hashin failure criterion

1- Introduction

According to the explosions that happened in the tanks of natural gas vehicles, the studies related to the simulation of impact load and explosion in this equipment and how to strengthen them against this type of loading have become more important and expanded. Compressed Natural Gas (CNG) with a pressure of about 200 bar is stored in the tanks of vehicles. If the safety points are not carefully considered in the design and construction of these tanks, they can explode and catch fire due to an impact.

Nowadays, composites are used in the construction of new-generation CNG tanks. The most important advantage of composite materials is that their properties can be controlled according to their applications. In addition, composites have very high corrosion resistance, low weight, and high specific strength compared to metals.

The laboratory investigation of the explosion is a suitable method, but at the same time it is expensive, therefore the simulation of the explosion using the finite element method is a very widely used and economical method. Several pieces of research have been conducted in the field of the explosion of thin-walled tanks and composite and multilayer shells. Rafiei and Torabi [1], to predict the explosive pressure of composite pressure vessels (with and without liner) exposed to internal pressure discussed and showed that Hashin's failure criteria and maximum stress predict the explosion with higher accuracy. Also, Kartal [2] used the experimental method and finite element analysis with the aim of estimating the explosive pressures and permanent volume increase of liquid gas storage tanks and compared the results of the explosion pressure and tank volume increase with the experimental results.

In the current research, the finite element simulation of the external explosion was investigated in 4 types of CNG tanks of cars. Simulation of the external explosion was done using the CONWEP model and Trinitrotoluene (TNT) material in two explosion points (near and far) and three different values of explosion charge in ABAQUS software.

2- Methodology

The tank studied in this research for all four types was a 75-liter tank with a radius of 178 mm and a length of 947 mm, which is subjected to an internal pressure of 200 bar [3]. Natural gas pressure tanks are divided into four types:

Type 1: These types of tanks are completely made of metal (Aluminum or steel).

Type 2: In these tanks, the Metal liner is reinforced by composite wrap-around.

*Corresponding author's email: a.albooyeh@du.ac.ir

Table 1. The layers' properties [4-6]

CNG Cylinder Type	Number of layers	The thickness of each layer (mm)	Composite thickness (mm)	Liner thickness (mm)	Total thickness (mm)
Type 1	1	8	-	8	8
Type 2	8	0.5	4	4	8
Type 3	8	1.5	12	2.5	14.5
Type 4	8	2.1	16.8	-	16.8

Table 2. The layers angles [4-6]

CNG Cylinder Type	Layers angles (from left to right)
Type 1	0
Type 2	$[90/90/90/90]_S$
Type 3	$[0/90/54/-67]_S$
Type 4	$[0/90/65/-70]_S$

Table 3. The mechanical properties of steel and Johnson-Cook constants [4]

E (GPa)	ν	ρ (kg/m3)	C_v (J/kg.K)	T_m(K)	T_0(K)
200	0.29	7830	477	1793	293
α (K^{-1})	A (MPa)	B (MPa)	$\dot{\varepsilon}_0\left(s^{-1}\right)$	C	m
0.000032	792	510	0.26	0.014	1.03
D_1	D_2	D_3	D_4	D_5	n
0.05	3.44	-2.12	0.002	0.061	0.26

Table 4. The Hashin parameters and mechanical properties of carbon-epoxy composite [7]

Density(kg/m^3)	1600
Orthotropic Properties	$E_1^0=153\text{GPa};\ E_2^0=E_3^0=10.3\text{GPa};\upsilon_{12}=\upsilon_{13}=0.3;$ $\upsilon_{23}=0.4; G_{12}^0=G_{13}^0=6\text{GPa};\ G_{23}^0=3.7GPa$
Strength(MPa)	$X^T=2537;\ X^C=1580;\ Y^T=82;\ Y^C=236;$ $S_{12}=90;\ S_{23}=40$
In-Plane fracture Toughness(kJ/m^2)	$G_{1C}^T=91.6;\ G_{1C}^C=79.9;\ G_{2C}^T=0.22$

Type 3: In these tanks Metal liner reinforced by composite wrap around the entire tank (full wrapped).

Type 4: These types of tanks are completely made of composite (carbon–epoxy). It having Light-weight, but more expensive than others.

Tables 1 to 5 show the specifications of the tanks and Fig. 1 shows the schematic view of tanks, layering, and position of explosion charge.

In order to ensure that these tanks do not fail under internal pressure, they were analyzed under hydrostatic pressure of 200 bar and the failure index of the tanks was compared.

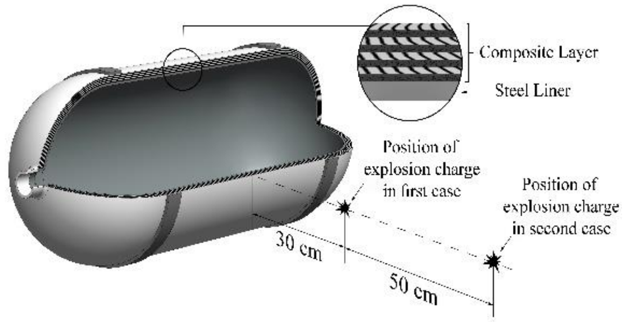

Fig. 1. Schematic view of tanks, layering, and position of explosion charge

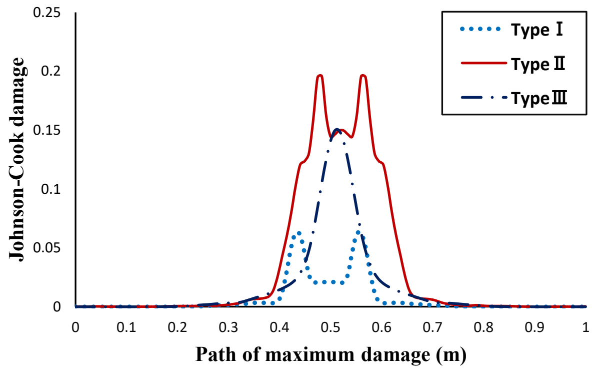

Fig. 2. The amounts of Johnson-Cook damage to the metal liner in the first case

Then the explosion loading was done on the tanks with an internal pressure of 200 bar for two explosion distances of 30 and 80 cm. To simulate the explosion load, the CONWEP explosion model was used with 1, 2, and 3 kg of TNT.

3- Results and Discussion

The results of static pressure showed that the failure index of none of the tanks exceeded 1 and all the tanks can withstand static pressure of 200 bar. Johnson-Cook damage criterion has been used to study the damage in the metal liner in type 1 to type 3 tanks. If the amount of damage of the elements in this criterion exceeds 1, it means that they are out of the plastic area and have been damaged and completely deteriorated. Also, the Hashin criterion was used to study the damage in the composite. Compressive and tensile damage is an indicator of the failure rate of composite fibers and matrix against blast load, which is defined based on plastic strain and destruction parameters and can have a minimum value of zero and a maximum value of 1. The closer the damage index of an element is to 1, the higher the damage rate of that element will be, and if it exceeds 1, it means that the elements have been completely destroyed by the blast load. Fig. 3 and 4 show the amount of damage caused to the metal liner and composite layer in the case of L=30 cm and m=1 kg.

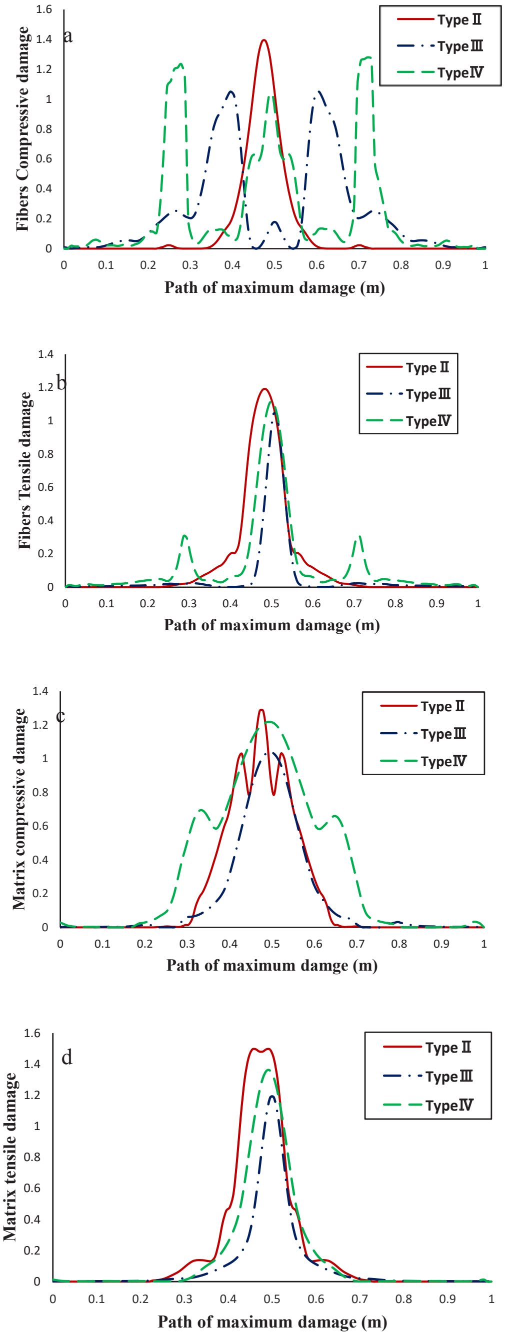

Fig. 3. The amounts of damage to the composite for the first case: a) fibers compressive damage,b) fibers tensile damage c) matrix compressive damage,d) matrix tensile damage

4- Conclusions

The fourth type tank has the strongest internal hydrostatic pressure compared to other tanks and can withstand up to 610 bar pressure, which is about 19.6%, 52.5%, and 38.6% more than first, second, and third type tanks, respectively. Although the first type of tank has a very good resistance against internal pressure and also the blast wave, but the very high weight of these tanks has caused the pressure tolerance in these tanks to be very low compared to the weight, which leads to applying extra load to the chassis and The results of Hashin's criteria showed that the most damage occurs in the composite of the second type tank and the third type tank has the highest safety against the external blast wave. In the second type of tank, there is a step at the junction of the composite to the tank, and the results show that due to the impact of the blast wave on this tank, the damage rate of the composite layers in this place increases suddenly. In general, the strain and damage caused by the blast wave in the metal liner of the second type tank are more than the first and third type tanks. Examining the results obtained in this research shows that the third type of tank has the best performance against the blast wave compared to other tanks. Due to the presence of a thin layer of metal liner in the third type tank, the weight of this tank is more than the fourth type tank, but the presence of this metal liner significantly improves the resistance of the tank against explosion.

References

[1] burst pressure in composite pressure vessels, Composite Structures, 185 (2018) 573-583.

[2] F. Kartal, Evaluation of explosion pressure of portable small liquefied petroleum gas cylinder, Process Safety Progress, 39(2) (2020) e12081.

[3] A. Ahmadnejad Nategh, CNG Vehicle Manual, Kahkeshane Danesh, 2016 (In Persian).

[4] M. Mashayekhi, Prediction of All-Steel CNG Cylinders Fracture in Impact by Using Damage Mechanics Approach, Scientia Iranica, 21(3) (2014) 609-619.

[5] E.B. Neto, M. Chludzinski, P. Roese, J. Fonseca, S. Amico, C. Ferreira, Experimental and numerical analysis of a LLDPE/HDPE liner for a composite pressure vessel, Polymer Testing, 30(6) (2011) 693-700.

[6] L. Zu, Design and optimization of filament wound composite pressure vessels, doctoral thesis, TU Delft, Netherland, 2012.

[7] Y. Shi, T. Swait, C. Soutis, Modelling damage evolution in composite laminates subjected to low velocity impact, Composite Structures, 94(9) (2012) 2902-2913.

HOW TO CITE THIS ARTICLE

A. Albooyeh, S. Amirabdollahian, N. Fatahi, Simulation and Analysis of the First to Fourth Types of Compressed Natural Gas Tanks of Vehicles under the Explosive Loading, Amirkabir J. Mech Eng., 54(8) (2022) 379-382.

DOI: 10.22060/mej.2022.20911.7335