THE ANALYSIS OF FIRE TEST FOR THE HIGH PRESSURE COMPOSITE CYLINDER

Chang Jong, Kim [1], Seung Hoon, Lee [2] and Young Gyu, Kim [3]

[1] Institute of Gas Safety R&D, Korea Gas Safety Corp, 332-1, Daeya-dong, Shihung-si, 429-712, South Korea, kimcj2009@kgs.or.kr
[2] Institute of Gas Safety R&D, Korea Gas Safety Corp, 332-1, Daeya-dong, Shihung-si, 429-712, South Korea, prooflee@kgs.or.kr
[3] Institute of Gas Safety R&D, Korea Gas Safety Corp, 332-1, Daeya-dong, Shihung-si, 429-712, South Korea, ygkim@kgs.or.kr

ABSTRACT

A large number of natural gas vehicles(NGV) with composite cylinders run in the world. In order to store hydrogen, using the composite cylinder has also reached commercialization for the hydrogen fuel cell vehicle(FCV) which is been developing on ECO Energy. Under these increasing circumstances, the most important issue is that makes sure of safety of the hydrogen composite cylinder. In case of the composite cylinder, a standards to verify the safety of cylinders obey several country's standards. For NGV, ISO 11439 has adopted as international standards, but for FCV, it has been still developing and there is only ISO/TS 15869 as international technical standards. In contents of international standards, the fire test is the weakest part. The fire test is that the pressure relief valves(PRD) normally operate or not in order to prevent cylinders bursting when a vehicle is covered by fire. However, with present standards, there is no method to check the problem from vehicles in local flame. This study includes fire test results that have been performed to establish the fire-test standards.

1.0 INTRODUCTION

World-wide concerns about the alternative energy resource are increasing due to the exhaustion of natural resource, global warming, environmental pollution, and so on. Hydrogen as an alternative energy has been considered as one of the clean energy in the future and replacement of traditional fossil fuel [1]. The US have studied for the safety codes and regulations related with hydrogen safety since 2003 [2]. Many EU countries and Japan have competitively made efforts on the development of the primary technology on infrastructure for hydrogen economy including hydrogen production, transportation and storage. Since 2005, the Korea government had declared the 'Hydrogen era' and built a master plan for hydrogen energy research. To make sure of safety of the hydrogen composite cylinder, many experts have been absorbed in their research, and they will concentrate continuously.

1.1 Standard and Regulation of the Fire Test

Following Table 1 shows a comparison of standard and regulation of the fire test for the composite cylinder. According to the standard and regulation the length of flame should be 1.65 meters, and over three thermal couples should be installed with a distance no more than 0.75 meters between each other. The maximum pressure in the cylinder, the time from the flame begin until the PRDs operate and the time to 1MPa inner cylinder after PRDs start ventilation must be measured during the test. With the points below, a test-result is judged whether success or failure.

- after ignition, the temperature must be over 590 degrees centigrade within 5 minutes
- approval by sufficient fire and gas release only through PRDs without burst

Table 1. Comparison of fire test standard and regulation.

Test	ISO/DIS 15869: 2008	SAE J2579:2008	UN ECE R-79
Test Procedure	Cylinder filled to WP ; equipped completely ; 100mm above fire source of 1.65m;PRD/valves/fittings shielded	Cylinder filled to WP ; equipped completely ; 100mm above fire source of 1.65m;PRD/valves/fittings shielded	Cylinder filled to NWP ;filled with H_2 or gas with higher thermal pressure build up ; equipped completely ; 100mm above fire source of 1.65m ; PRD/valves/fittings shielded
Requirements of monitoring	Arrangement of fire ; surface temperature sat at least 3 locations (less 0.75m distance) ; pressure ; max. pressure ; time to venting start and time of evacuation to 10bar	Surface temperatures (of at least 3 locations) ; temperature recording intervals<10sec ; time span from of ignition to initiation ; max. pressure ; release time to 10 bar	Surface temperatures (of at least 3 locations) ; temperature recording intervals<10sec ; time span from of ignition to initiation ; max. pressure ; release time to 10 bar
Requirements for approval	Fire : 590°C within 5min. after ignition ; cylinder : gas release through PRD without rupture	Fire : 590°C within 5min. after ignition ; cylinder : gas release through PRD without rupture	Fire : 590°C within 5min. after ignition ; min temperature 590°C
Results (approval/rejection or other measures to be taken)	Approval by sufficient fire and gas release only through PRD without burst. Cylinders with thermal insulation must endure 20 min. bonfire without burst. PRD demounted (2samples)	Approval by sufficient fire and gas release only through PRD without burst.	Approval by sufficient fire and gas release only through PRD without burst.

1.2 Procedures of the Fire Test

Those standards and regulations in Table 1 were developed by CGA C14, fire test standard of the metal cylinder. They do not include properties of the composite cylinder. For example, thermal conductivity is much different. Especially it is difficult to deliver heat from localized fire to the PRD in the composite cylinder. The PRD may not work because temperature cannot reach to operating level. That is the reason why we cannot confirm problem of localized fire for the composite cylinder. Recently, many countries, which are aware of the importance of the fire test, are developing the advanced fire test. Among them GTR(vehicle regulation) in UN ECE WG29 suggests a new standard about the fire test. The proposal, from UN ECE WG29, includes the followings.

- fire test should be independent of external wind
- localized fire 5 min.(at 600℃) / Full fire (at 800℃)

Following Figure 1 shows the standard of the fire test from UN ECE WG29.

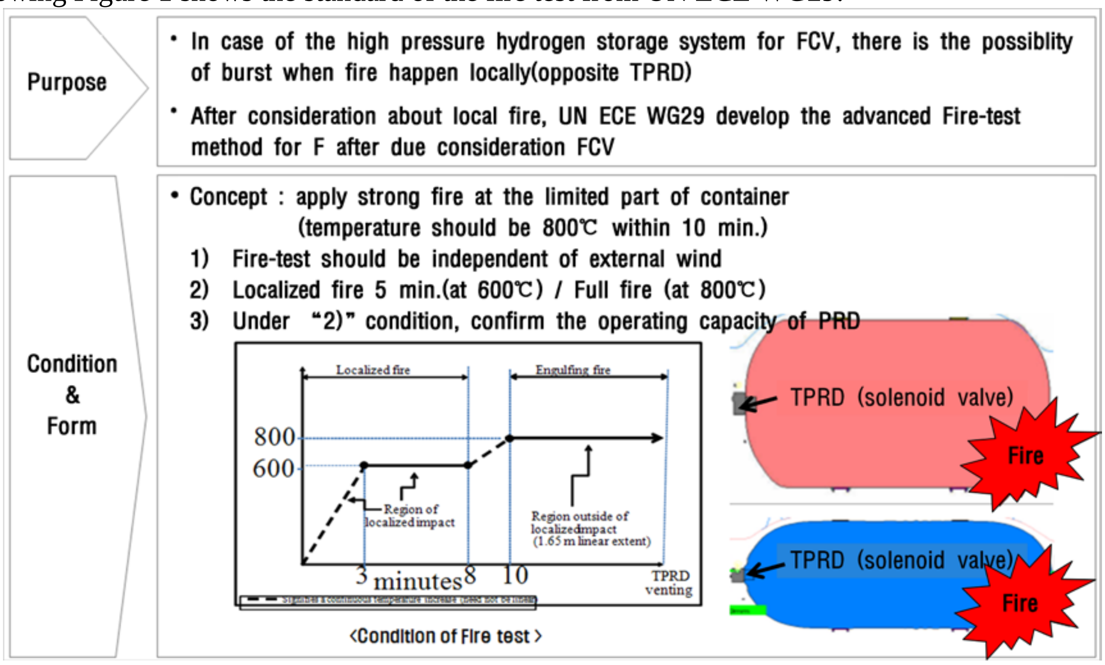

Figure 1. Fire test standard in UN ECE WG29.

2.0 EXPERIMENTS

In order to establish the fire-test, the first experiment was performed in 2010. The fire-test was performed with composite cylinders for CNG. Total 6 cylinders(each two classified by cylinder typeⅡ,Ⅲ,Ⅳ) were tested. The wide place, where nobody is around, was selected for the test.

2.1 Experimental Setup

The fire test was performed in accordance with NGV2, which is the same method with the standard of the composite cylinder for FCV. Following Figure 2 shows the concept of performed-test.

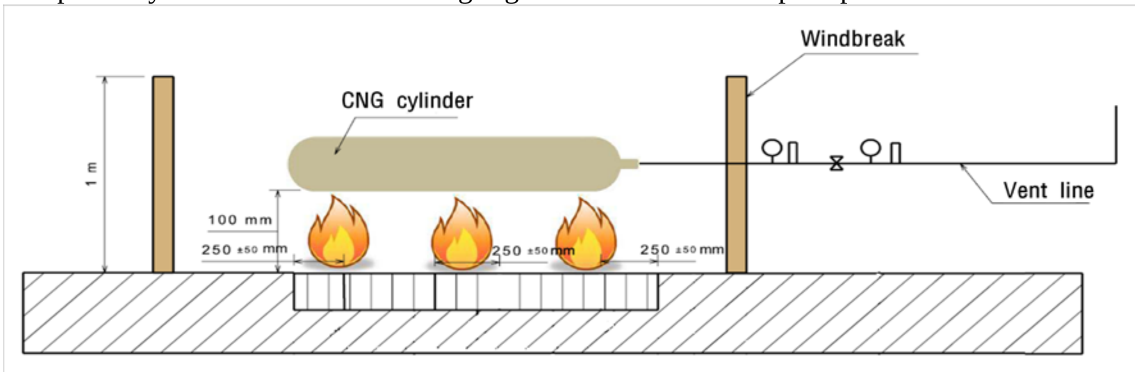

Figure 2. Concept of the fire test.

In case the cylinder may be exploded on bonfire test and PRD may not operated, ground was dug to about 50 centimeters and emergency vent line was installed. Also, to protect the fire source and temperature change from wind, the windbreak is installed. The preparing bonfire test is as below(Fig 3).

Figure 3. Preparing fire test.

Surface temperature was installed by five thermocouples located along the bottom of the cylinder and spaced not more than each 10 centimeters apart according to ANSI/NGV2-2007. Also metallic shielding for valve and PRD was used to prevent direct flame impingement. Surface temperature was monitored through total seven thermocouples with each one thermocouple on valve and cylinder. A pressure sensor was installed on the vent line to prevent the explosion of cylinder when the pressure of inner tank was highly increased. Figure 4 shows installed sensors and a vent line.

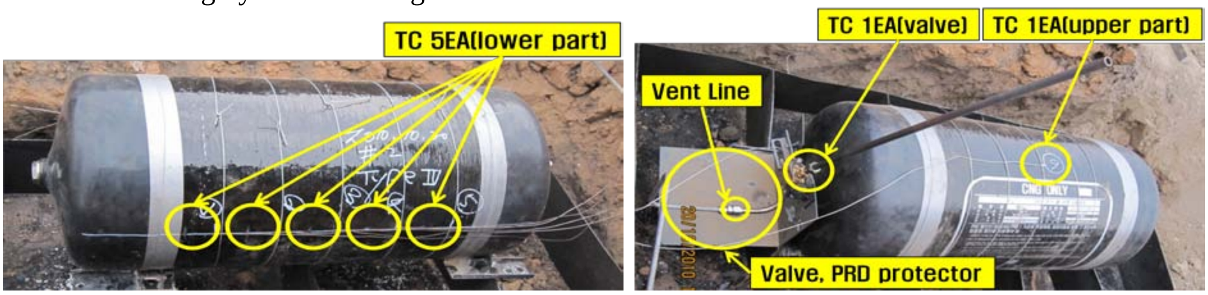

Figure 4. Installed sensors and a vent line.

The fire test contests following,

- test location: The mouth of Mankyung river in KIMJE, Korea.
- test date: Oct. 11~ 22. 2010 (2 weeks)
- test cylindes: TypeⅡ cylinder 2EA, TypeⅢ cylinder 2EA, TypeⅣ cylinder 2EA
- fire source: gasoline + kerosene
- test regulation: ISO 15869, ANSI/NGV 2-2007
- TC sensors: located along the bottom of the cylinder 5EA, on cylinder 1EA, on valve 1EA
- pressure sensor: 1EA

2.2 Measurement

To stably record the data during the fire test, 30 m compensating lead wire was connected with DAQ which was produced in NI, and all data were saved through Labview program(Fig 5).

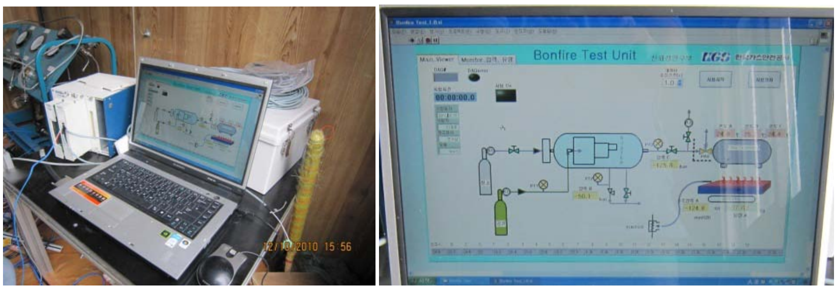

Figure 5. DAQ(National Instrument) & Labview program.

3.0 RESULTS AND DISCUSSION

Tests were performed on 2 cylinders per each type. The fire source was made from gasoline and kerosene in a ratio of 7:3. Figure 6 show the fire test of various type and Figure 7 show test results of the fire test..

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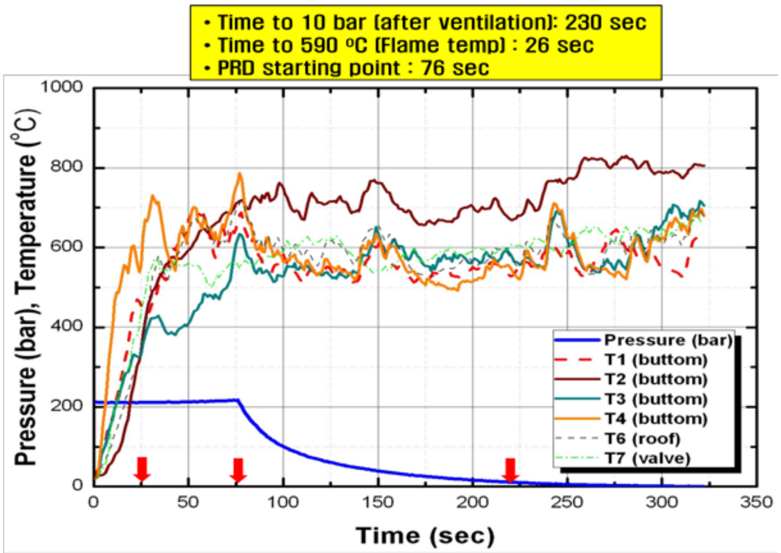
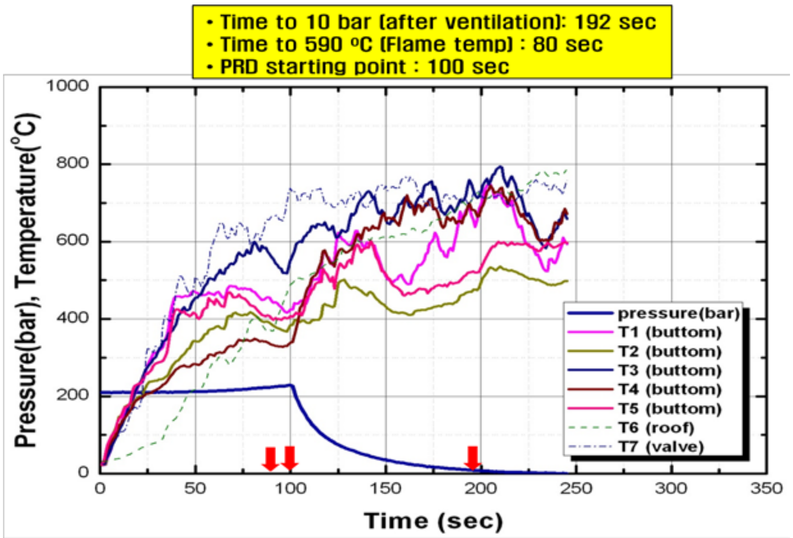
[TypeⅡ] [TypeⅢ] [TypeⅣ]

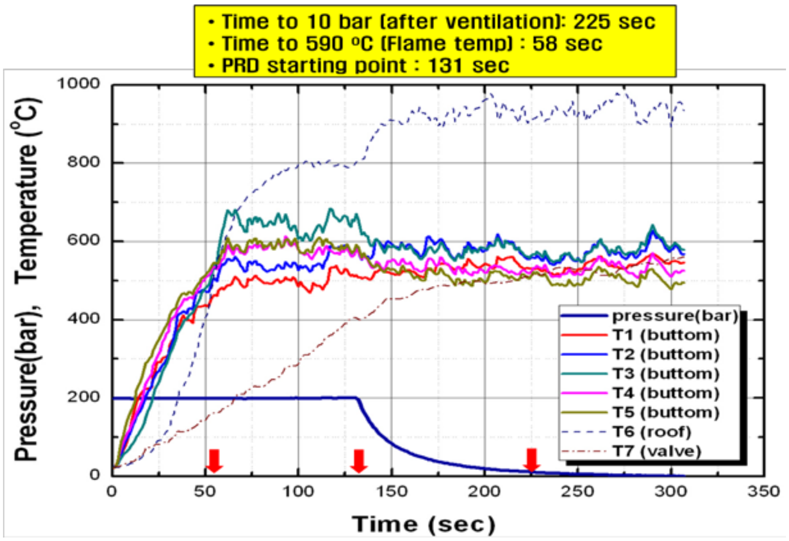
Figure 6. The fire test of various cylinder types.



(a) TypeⅡ cylinder.



(b) TypeⅢ cylinder.



(b) TypeⅣ cylinder

Figure 7. Test results of various type cylinders.

As test results, the PRD venting time of TypeⅡ was the shortest because only the body part was wrapped by the glass resin. In case of TypeⅢ cylinder made of metal liner was shorter than TypeⅣ cylinder used HDPE(High Density Poly Ethylene) liner because metal liner of TypeⅢ cylinder is easy to transfer the heat and composite thickness of TypeⅣ cylinder is thicker. As table 2 shows below, pressure variation of inner cylinder of TypeⅡ cylinder was the lowest, and TypeⅢ was lower than Type Ⅳ cylinder because TypeⅣ cylinder is hard to transfer the heat.

Table 2. Summary of fire test results.

	Type Ⅱ	Type Ⅲ	Type Ⅳ	comparative analysis
Time to 10bar (sec)	230	192	225	Depend on cylinder volume & PRD capacity
Time to 590℃ (sec)	43	80	58	Need advanced study
PRD starting point(sec)	76	100	131	Depend on liner material
Change of pressure(bar)	5	9.2	1.6	Need advanced study

4.0 CONCLUSIONS

In this research, we performed bonfire test to compare and to find out differences of PRD performance on each type. The PRD venting time of TypeⅡ was the shortest, and TypeⅢ cylinder was shorter than TypeⅣ. As table 2 shows, pressure variation of inner cylinder of TypeⅡ cylinder was the lowest, and TypeⅢ was lower than Type Ⅳ.

These results suggest that current regulation of bonfire test is incorrect because test method of each type cylinder has to be performed differently. Especially, if The fire source initiates under the localized exposure area of TypeⅢ, Ⅳ cylinder, PRD which is only controlled in temperature may not operate and may rupture in this situation. Therefore, the regulation of fire test need to add ″the localized fire test″ for safety of composite cylinder. Moreover, the metal shielding which transfers the heat is installed or it needs to install the additional PRD in both end parts of cylinder. It will be performing additional tests to establish the regulation of fire test. We suggest that revision of international regulation will be proceeded based on these test results.

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