Letter

Ignition by a collision of LOX and LNG

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Abstract

The explosion generated by the collision of LOX and LNG on a solid surface was investigated. The experiment was conducted in a free field. Dewar vessels filled with LOX and LNG fell freely onto the ground surface from a height of 50 m. The experimental results show that ignition was confirmed at the moment of contact between LOX and LNG, while the Dewar vessels were destroyed by the collision. Furthermore, due to the crater left in the ground surface after the explosion, it is suggested that LOX and LNG burn violently.

Keywords : LOX, LNG, collision, ignition, explosion

1. Introduction

In the last few years, there has been increasing interest in the mixture of liquid oxygen (LOX) and liquefied natural gas (LNG), which is a candidate for rocket propellant systems[1), 2)]. The Japan Aerospace Exploration Agency (JAXA) has been conducting a safety evaluation of a rocket using a LOX/LNG propellant system[3)]. While the rocket is launching, one of the accident scenarios is that the rocket falls freely onto the ground surface because of any trouble in the propellant system. Owing to the collision between the rocket and the ground surface, both LOX and LNG (fuels) in the rocket are scattered on the ground surface. When LNG is mixed with LOX, there is a high risk of an explosion. Previous studies show that a LOX and LNG mixture (LOX/LNG) is one of detonable materials[4)]. At the same time, the vapor cloud that is formed by the evaporation of the fuels can be easily ignited because it has very low minimum ignition energy[5)]. Therefore, the formation of LOX/LNG indicates a high potential for hazard resulting in accidental explosions that can cause serious damage to human beings or facilities over a large distance. Unfortunately, however, the ignition conditions of LOX/LNG are not known well.

For the first step in the safety evaluation process of launching a rocket, this study investigates the strength of the explosion generated by the collision of the fuels on the ground surface. The collision was created by simulating a free-fall experiment in which the fuels are dropped from a height of 50 m onto the ground surface. The height of 50 m was decided based on the worst-case scenario which was estimated by JAXA.

2. Experimental

Figure 1 shows the setup of the field experiment on the free fall LOX and LNG using the remotely operated releasing unit. The height of the fuels was 50 m, so that the velocity at the ground surface was approximately 30 $m \cdot s^{-1}$. The experiment was initiated when the unit released the fuels. To repeat the collision point of the fuels onto the ground surface, a steel wire guided the fuels from the crane to the ground. At the ground surface, there was a collision plate on the concrete floor. The collision plate (1000 × 1000 × 10 mm) was made of aluminum alloy (A52S) or stainless steel (SUS 400).

Two Dewar vessels, one containing LOX and the other LNG, were set in the steel cage. The inner and outer diameters and the volume of the vessels were 140 mm, 160 mm and 0.014 m^3. The Dewar vessels were made of glass to allow them to be easily destroyed by the collision. The Dewar vessels were supported by a plastic supporting ring and wooden grids. The wooden grid was fixed to the steel cage, which was fixed to the remotely operated

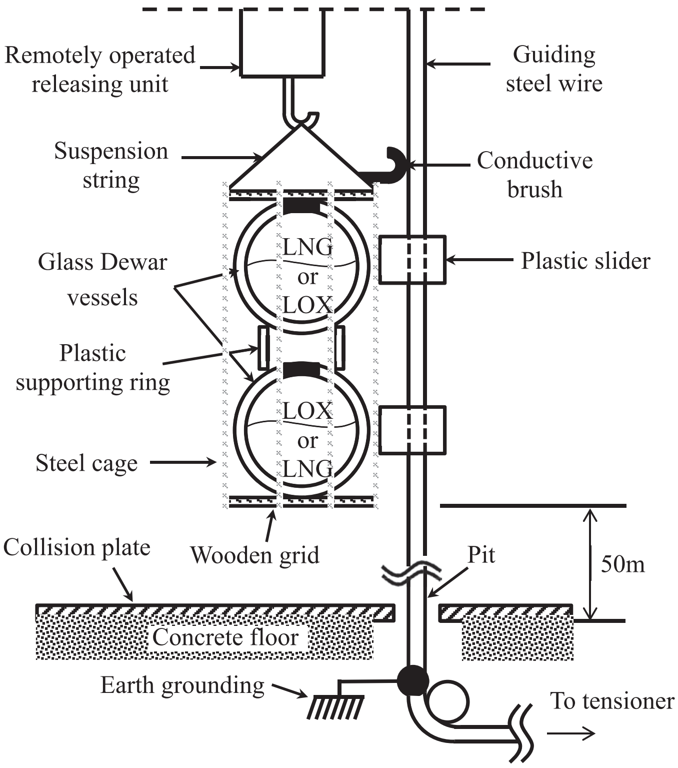

Figure 1 Experimental setup for drop test.

releasing unit and the guiding steel wire by a suspension string and a plastic slider. When the cage impacted at the ground surface, the supporting ring and the grids were easily destroyed, allowing the Dewar vessels with the fuels to smoothly collide head-on with the ground surface. In all experiments, countermeasures were taken to prevent static electricity because it is a potential unwanted ignition source. Figure 1 also shows the conductive brush and the earth connection. The steel cage and the guiding steel wire were connected by a conductive brush, and the guiding steel wire was connected to the ground. Therefore, while the fuels were falling freely, all experimental units maintained the same electric potential to ground.

In order to ignite the vapor cloud that is formed by the evaporation of the fuels after the collision, a gas explosion was used as the intentional ignition source at the collision point. The rubber balloons with the gas mixture of methane and oxygen were set at a distance of 1.7 m from the collision point. Several grams of the stoichiometric gas mixture were ignited at the center of the balloon by a hot surface of fused Nichrome wire as done in a previous study[6].

To investigate the collision moment, an acceleration sensor was set in the collision plate. An acceleration sensor (Fuji Ceramics Corporation BNCP-ZR or PCB M350B04) was set in the collision plate. The signal from the acceleration sensor was used as a trigger signal of the pulse generator (DG535). The time delay from the collision to the intentional ignition of the gas in the balloon was 1000 ms because it takes some time for LOX and LNG to scatter and to mix after the collision. The signal of the pulse generator also triggered a high-speed video camera (Vision Research, Phantom v640) to observe the explosion phenomenon at 10,000 fps.

Table 1 shows the experimental conditions for the collision test. The initial masses of LOX and LNG in each Dewar vessel were determined prior to the experiment based on a measurement of the rate of evaporation mass loss because there is a time interval between when the fuels are set up and the moment of the collision. The corrected masses of LOX and LNG at the time of the collision, which were determined by considering the evaporation rate, are shown in Table 1. Experiment number (Exp.) 1 had a mass of approximately 468 g of the stoichiometric composition. The full masses of Exps. 2, 3, 4, and 5 were approximately 1.6 kg of the stoichiometric composition. The collision speeds were approximately 28 $m \cdot s^{-1}$. Two kinds of materials for the collision plates were used with aluminum for Exps. 1 and 2, and stainless steel for Exps. 3, 4, and 5. In Exp. 4, the positions of the fuels were changed, with LNG was on top and LOX was on bottom. The balloon for intentional ignition source was set up in Exp. 1, 2 and 3, not in Exp. 4 and 5. In Exp. 5, conductive tape was attached to the surface of both glass Dewar vessels with the intention of reducing static electricity that may be generated by the shattered glass at the moment of impact.

3. Results and discussions

Illustrative framing images obtained with a high-speed video camera during the collision between the fuels and the ground surface are shown in Fig. 2. The numbers in the pictures represent the elapsed time from the signal of the acceleration sensor. After the lower Dewar vessel was destroyed completely, some visible light was confirmed when the top Dewar vessel began to shatter. It is considered that the ignition occurs when LOX and LNG come into contact with each other.

Table 1 Experimental conditions for collision test

Exp.	Corrected mass [g]		Collision Speed [$m \cdot s^{-1}$]	Collision plate	LNG location	LOX location	Balloon for ignition
	LNG [g]	LOX [g]					
1	93	375	28.5	A52S	Bottom	Top	Set−up
2	371	1298	28.3	A52S	Bottom	Top	Set−up
3	335	1299	28.2	SUS400	Bottom	Top	Set−up
4	314	1293	28.1	SUS400	Top	Bottom	−
5	322	1288	27.9	SUS400	Bottom	Top	−

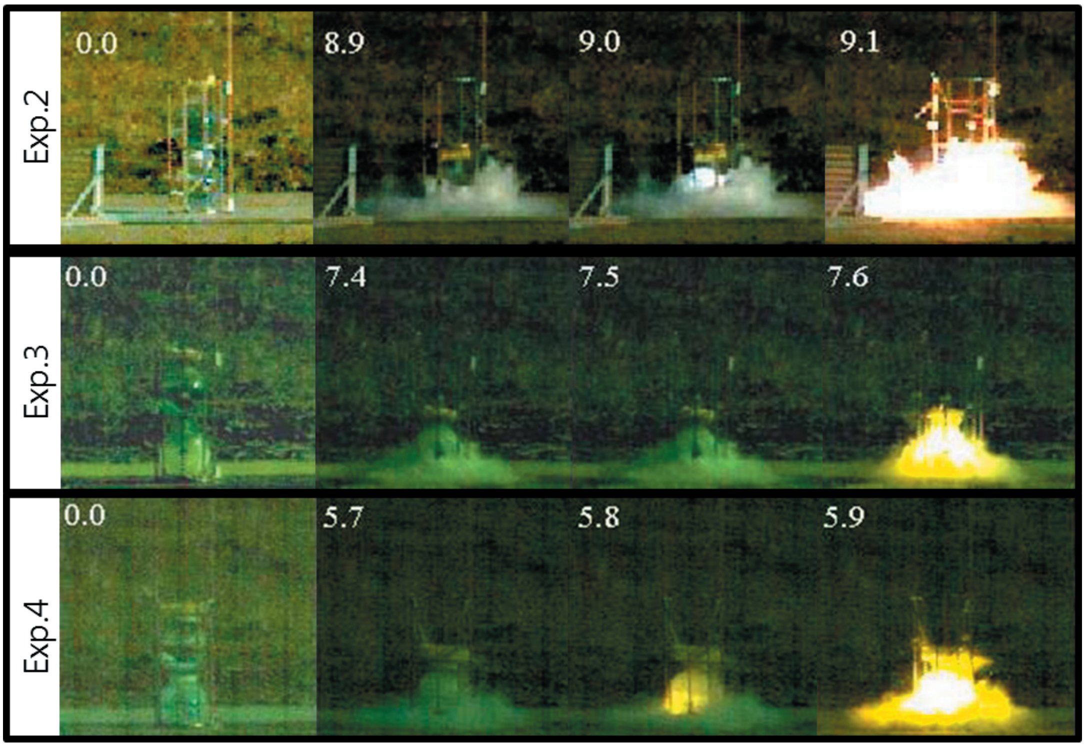

Figure 2 Framing images obtained with a high-speed camera during the collision (unit : ms)

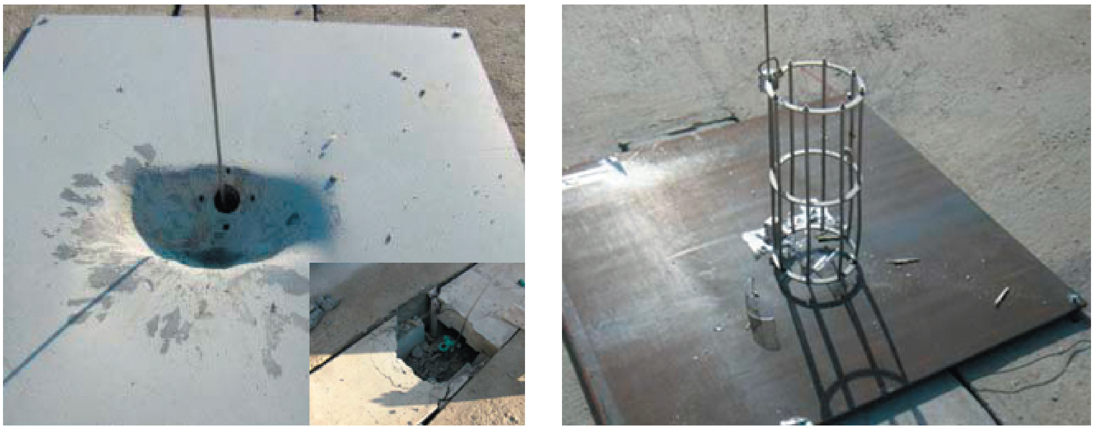

Figure 3 Collision plates of Exps. 2 and 3 after the experiment.

For example, in the case of Exp. 3, the ignition should occur between 7.5 and 7.6 ms because the image obtained at 7.6 ms clearly shows a visible bright light. It was mentioned previously that the signal for the ignition of the gas mixture in the balloon was delayed by 1000 ms from the signal of the acceleration sensor. Therefore, it is clear that the explosion of the fuels was not ignited by the gas explosion. Furthermore, even though the balloon for ignition was not set in Exp. 4, the occurrence of a bright light at 5.8 ms (or 5.9 ms) was confirmed. Although the results of Exps. 1 and 5 are not shown here, we also confirmed bright spots in the framing images within several milliseconds. With all the results, it is concluded that the ignition occurred at the initial stage of the collision between LOX and LNG without any intentional ignition source. It would be interesting to investigate into the ignition source of the explosion. Further study is required.

Our next concern is whether the explosion is detonation or deflagration. Figure 3 shows the deformation of the collision plate after the experiment. The result of Exp. 2 shows that the collision plate became intensely strained and deformed. Furthermore, some parts of the plate even display cracks. The deformation geometry of the aluminum plate corresponds to the geometry of the concrete construction under the plate. The results of Exp.1 were similar to those of Exp. 2. Such heavy deformations of the collision plates suggest that LOX and LNG burned violently. The results of Exp. 3 with the stainless steel collision plate, however, show little deformation, suggesting that no detonation-like burning occurred. The results of Exps. 4 and 5 were similar to that of Exp. 3.

Unfortunately, the reason for different deformation is not clear in this study. Two possibilities are considered. One is that chemical material properties of the plate make the different reactions. It is known that aluminum is a reactive metal. The other is that the different strength of the plate makes a different deformation. Young's modulus of the steel is about 30 times higher than that of the aluminum. Further study is required.

4. Conclusions

The explosion phenomenon induced by LOX and LNG freely falling from a height of 50 m was investigated. After the Dewar vessels containing the fuels were destroyed by the collision with the ground surface, when LOX and LNG came into contact with each other, the ignition is confirmed. Furthermore, the deformation of the aluminum collision plate suggests that the LOX and LNG burned violently.

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