EXPERIMENTAL INVESTIGATION INTO WATER-FILLED PRESSURIZED VESSELS DAMAGED BY HIGH-VELOCITY PROJECTILE IMPACT

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ABSTRACT

All spacecraft in orbit are susceptible to high velocity impact by meteoroid and space debris. Pressure vessels are the most critical components onboard spacecraft. Impacts of meteoroid or space debris on pressure vessels can indeed lead to the rupturing failure of the vessel and terminate prematurely spacecraft mission. The aim of this work is to explore experimentally the condition and the limit between simple perforation and rupturing damage of pressure vessels under high velocity impacts. Preliminary results are presented from high-velocity impact tests on thin-walled aluminum and steel cylindrical pressurized vessels filled with different percent volume of water and different pressure of gas. Damage patterns and mechanisms leading to rupturing failure are discussed.

1. INTRODUCTION

Increasing amounts of space debris have put spacecraft at a greater risk of sustaining high velocity impacts. Pressurized spacecraft components, especially pressure vessels designed primarily as containers to store liquids or gases and often times a mixture of both gas and liquid containing energy in the form of pressurized gases and liquids (e.g. for breathing gases, water, propellant storage, etc.) are the most critical components onboard spacecraft. Impact damages from high velocity impacts on pressurized vessels were found to be rather complex: they ranged from simple perforation to catastrophic rupture of complete vessels. Impact damage modes include leakage, cracking and catastrophic rupture [1~3,5]. It can lead to premature termination of the mission, and to the creation of more space debris. Even if catastrophic rupture does not occur, perforation of a vessel can jeopardize spacecraft control due to venting of the pressurized contents. It is therefore necessary to explore experimentally the condition and the limit between simple perforation and rupturing damage of pressure vessels under high velocity impacts. Preliminary results are presented from high-velocity impact tests on thin-walled aluminum and steel cylindrical pressurized vessels filled with different percent volume of water and different pressure of gas. Damage patterns and mechanisms leading to rupturing failure are discussed.

2. EXPERIMENTAL SET-UP

The experimental investigation of high velocity impact on water-gas filled pressurized vessels and gas-filled pressurized vessels is performed at velocity of around 3 km/s with cylindrical aluminum projectile at Harbin Institute of Technology two-stage light gas gun system. The cylindrical projectile diameter was 5.4mm, with long/diameter (L/D) of 1.0 and 0.5, impacted on vessels at normal incidence in the center along the cylindrical vessels' axial. In order to simulate the space debris, the projectile material for the experimental test was chosen to be aluminum. The experimental set-up is schematically displayed in Fig.1. The test articles consisted of aluminum soft drink cans and small steel coolant cans. The test articles were installed in the chamber vacuumed to 10 mm Hg. The impact velocity of projectile were obtained by measuring the peak time difference _t of trigger pulse of two-condenser discharge. The two condenser are placed in front of the pressure vessel, spacing L1 is 200mm, then velocity V=L1/_t is obtained.

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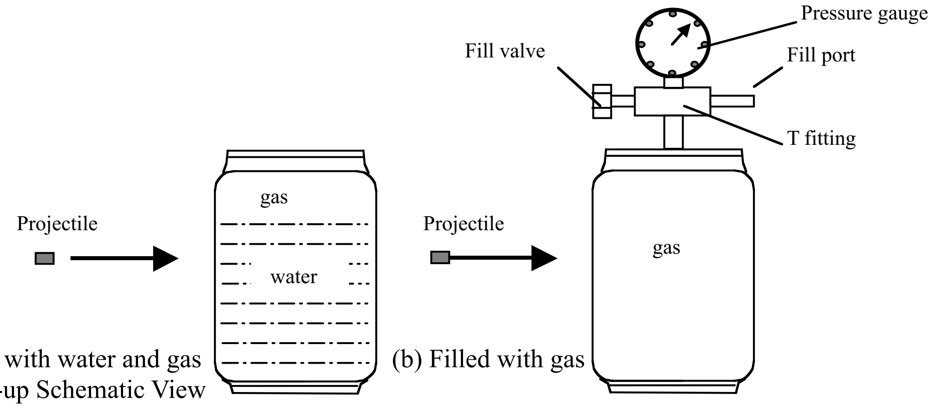
Tests were conducted first on steel coolant cans filled with air at 1 atmospheric pressure and different volume of water as illustrated in Fig.1 (a). The can was sealed with epoxy. The test was to investigate the effect of impact site to the catastrophic rupture.



(a) Filled with water and gas (b) Filled with gas

Fig.1 Experimental Set-up Schematic View

Tests were also conducted on aluminum cans filled with nitrogen at up to 4 atmospheric pressure to investigate the effect of filled-gas pressure to the catastrophic rupture. Pressure was monitored and verified before testing using a pressure gauge as illustrated in Fig.1 (b). Tubing was sealed to the can at one end with epoxy, and a T-fitting attached to the other end provided access for the pressure gauge and a fill valve.

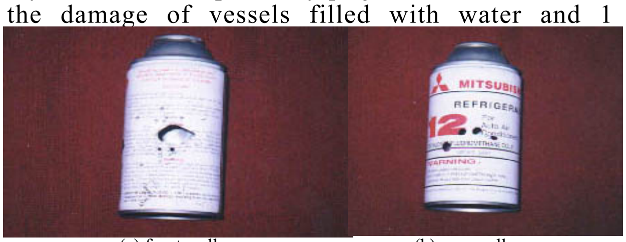
3. EXPERIMENTAL RESULTS AND DISCUSSION

The representative results of the high velocity impact test are presented in tables 1 and 2. In Table 1, test

Table 1 High Velocity Impact Test Results for Water and Gas Filled can

Test number	L/D	Velocity Km/s	Impact site	Catastrophic rupture
1	0.56	2.83	Gas	No
2	0.56	2.90	Gas	No
3	0.56	3.10	Gas	No
4	0.56	2.72	Water	Front
5	0.56	2.93	Water	Front
6	0.56	2.95	water	Front

results are presented for water and gas filled cans only. From the results of table 1, the damage of water and gas filled can were front wall and rear wall perforation when projectiles impact on cans above the water, the impact damage is same as the damage of can filled with 1 atmospheric pressure gas only as shown in Fig.2. When projectile impact on cans below the water, the impact damage is different from the damage of cans filled with gas of 1 atmospheric pressure, has the front wall catastrophic rupture as shown in Fig.3. That is to say that the site impacted by projectile has an effect on the damage of vessels filled with water and 1



(a) front wall (b) rear wall

Fig.2 Damage of Water and Gas Filled Can Impacted at The Site above The Water

Fig.3 Damage of Water and Gas Filled Can Impacted at The Site under The Water

atmospheric pressure gas. The damages are same as water filled pipes and heat radiator panels impacted by projectile, illustrated in Fig.4 and Fig.5, have the impacted site catastrophic rupture. These can be explained by the hydraulic ram crack initiation theory proposed by Rosenberg, Bless,and Gallagher [3,4]. Projectile impact on water and gas filled cans at the site under the water initiates a hydraulic ram effect, that is to say, when projectile impacted on pressure vessels at the

Fig.4 Damage of Water Filled Pipes Impacted by Projectile

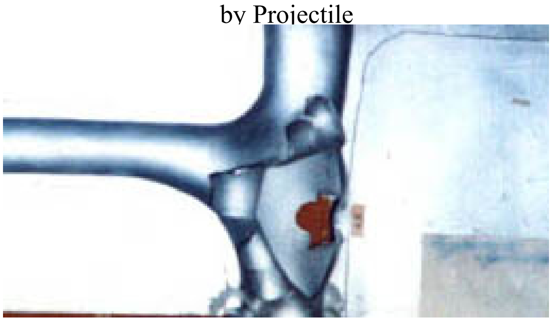


Fig.5 Damage of Water Filled Radiation Panels Of heat Impacted by Projectile

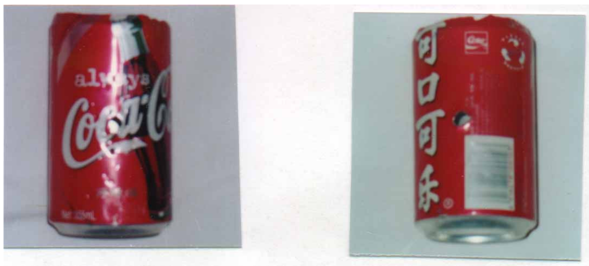
Table 2 High Velocity Impact Test Results for Gas Filled Cans

Test number	L/D	Velocity km/s	pressure MPa	Damage	
				Front	Rear
1	0.56	2.83	0.0	Perf.	Perf *.
2	0.56	2.90	0.0	Perf.	Perf.
3	0.56	3.10	0.10	Perf.	Perf.
4	0.56	2.72	0.20	Perf.	Perf.
5	0.56	2.93	0.25	Perf.	Perf. *
6	0.56	2.95	0.30	Perf.	Rupt.
7	1.0	2.85	0.30	Rupt.	Rupt.
8	1.0	2.92	0.30	Rupt.	Rupt.
9	0.56	2.91	0.35	Perf.	Rupt.
10	0.56	2.84	0.40	Perf.	Rupt.

*Here Perf. Is abbreviation of perforation; Rupt. is rupture.

liquid region, the shock pressure will be generated. This hydraulic ram then initiates bulging and cracking around the impact hole, catastrophic rupture will occur.

In Table 2, test results are presented for nitrogen filled cans at up to 4 atmospheric pressure. Tests were conducted on empty, un-pressurized cans that were left open to the vacuum of the test chamber. These tests have the front-wall and rear-wall perforation with crack as shown in Fig.6, demonstrate the size of damage produced by projectile impact on front-wall and rear-



Front Rear

Fig.6 Front and Rear Wall Damage of Un-Pressurized Can

wall in the absence of gas. As the impact velocity is lower, the projectile impacted on front-wall is not fragmented, will perforate the rear-wall. By removing the effects of the gas and the static stresses, a basis for comparing tests on pressurized cans was obtained. When the cans are filled with nitrogen, as the pressure within the can increase, the stress in the wall increase, the damage are different at basically identical impact condition. Catastrophic rupture is defined to have occurred if unstable fracture produces fragmentation or unzipping of the can. Fragmentation occurs when cracks in the can intersect to split the can into 2 or more large fragments. Unzipping is a term that means a long crack extends the majority of the distance down the length of a can or around the circumference of the can. It was observed that catastrophic rupture followed basically the same series of events. After the impact stresses have died out, the crack is acted upon by only the initial static stresses due to pressurization. If the flaw induced by impact stresses exceeds the critical flaw size value, catastrophic rupture will occur, otherwise further growth of the flaw will not occur. When pressure within the can large than 2.5 atmospheric pressure, the catastrophic rupture occurred from the rear-wall or front-wall. These can be seen from Fig.7 and Fig.8. Fig.7 is rear-wall catastrophic rupture. Fig.8 is front-wall and rear-wall catastrophic rupture. From Fig.8 it can be seen that if the kinetic energy of projectile is large will produce the front-wall and rear-wall catastrophic rupture. That is because large L/D of projectile will produce large hole-size on front-wall and rear-wall [6,7]. As observed in Table 2, the critical pressure for catastrophic rupture under the test condition is 2.5 atmospheric pressure, if the pressure small than this value catastrophic rupture will not occur, if the pressure large than this value

Fig.7 Rear Wall Catastrophic Rupture
Of Pressurized Can

(a) Front-Wall Catastrophic Rupture

(b) Rear-Wall Catastrophic Rupture
Fig.8 Rear-Wall and Front-Wall Catastrophic Rupture
Of Pressurized Can

catastrophic rupture will occur.

4. CONCLUSION

For the test condition used during this work, the following conclusion can be obtained:
The site impacted by projectile on the vessels has an effect on the damage of vessels filled with water and 1 atmospheric pressure gas. When projectile impact on vessels above the water, the impact damage is same as the damage of vessel filled with 0.1MPa gas only, has front wall and rear wall perforation. When projectile impact on vessels below the water, the impact damage is different from the damage of vessel filled with gas, has the front wall catastrophic rupture.
The internal pressure has a great effect on the catastrophic rupture of vessels filled with gas when impacted by projectile. The critical pressure for catastrophic rupture under the test condition is 2.5 atmospheric pressure, if the pressure small than this value catastrophic rupture will not occur, if the pressure large than this value catastrophic rupture will occur. If the pressure large than the critical pressure and the kinetic energy of projectile is larger, the front-wall and rear-wall catastrophic rupture will occur. The same results will be obtained when projectile impacted on water and gas filled cans at the site above the water with the gas pressure large than critical pressure.

5. REFERENCES

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