Destruction of Old or Abandoned Chemical Weapons by Controlled Detonation

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Abstract

While a large part of the world's stockpile of chemical weapons has been destroyed already, the destruction of non-stockpiled chemical weapons will continue in the future. Dismantling non-stockpiled chemical munitions such as old/abandoned chemical weapons is a very difficult task and involves a high risk of accidents. Controlled detonation is suitable for old/abandoned chemical weapons, since it can destroy chemical munitions without prior dismantling. In controlled detonation, the shells of chemical munitions are fragmented, and the chemical agents and explosives filling the shells are destroyed by the shock wave, as well as by the high-pressure and high-temperature environment produced by the detonation of the donor charge. A detonation chamber and a controlled detonation system, whose main component is the detonation chamber, have been developed and used in destroying many old/abandoned chemical weapons in and out of Japan since 2004. The controlled detonation system and destruction of chemical weapons are outlined in this report.

Introduction

Chemical weapons were first used in 1915 during World War I. Since then, many countries have developed, produced, retained, and used chemical weapons. In areas that were battlefields in the past, they are still found as unexploded munitions. In addition, chemical weapons, dumped in the territory of a country by the country itself or abandoned by another country, have been found in the ground as well as in water, and this has become a problem, not only for the safety and health of the residents, but also for the local environment and economic activities.

Following the entry into force of the 1997 Chemical Weapons Convention, which obliges Japan to destroy abandoned chemical weapons in China, the Engineering Business of Kobe Steel conducted technical research and development aimed at taking part in this destruction project. Since receiving an order for the treatment of the chemical munitions left by the old Japanese armed forces and found in Lake Kussharo (Hokkaido) in 2000, the company has been performing chemical weapons destruction in various ways. In particular, the company has detoxified many old or abandoned chemical weapons using a controlled detonation system developed in-house, called DAVINCH™ Note), and has also provided its customers with destruction facilities which utilize the controlled detonation system.

This article introduces Kobe Steel's DAVINCH™ system and also outlines chemical weapons and chemical weapon destruction performed by the DAVINCH™ system.

1. Chemical weapons

1.1 What are chemical weapons?

In a broad sense, chemical weapons are munitions for killing or incapacitating humans with chemical substances. As mentioned above, modern chemical substances with high toxicity were first used as weapons of mass destruction during World War I. In early days, chlorine gas was simply put on the wind and flowed toward the enemy; but soon, projectiles filled with toxic chemical substances (chemical agents) were fired with artillery, for example, to efficiently deliver them to the enemy. The projectile also contained built-in explosives such as a burster for opening the munitions shell to scatter and evaporate chemical agents.

After that, each country competed to develop chemical agents and the means to deliver them to the enemy (projectiles, bombs dropped from aircraft, etc.), and chemical weapons diversified rapidly. Famous chemical agents such as phosgene (molecular formula, $COCl_2$; NATO code, CG) and mustard gas (molecular formula, $(CH_2CH_2Cl)_2S$; NATO code, HD) had already been used during World War I. In addition, during World War II, the old Japanese armed forces manufactured, in large quantities, a mixture of HD and lewisite (molecular formula: $CHCl = CHAsCl_2$, NATO code: L), called a Kii (yellow) agent, and diphenylcyanoarsine (molecular formula: $(C_6H_5)_2AsCN$, NATO code: DC) and/or diphenylchloroarsine (molecular formula: $(C_6H_5)_2AsCl$, NATO code: DA), called Aka (red) agent. During the Cold War after World War II, sarin and VX, which have stronger toxicity, were also manufactured and stockpiled in large quantities in the former Soviet Union, the United States, and other countries.

Note) DAVINCH is a registered trademark of Kobe Steel, Ltd.

1.2 Chemical Weapons Convention

The Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (hereinafter referred to as the "Chemical Weapons Convention") was adopted in 1992 and entered into force in 1997. There are 193 states parties to the convention, and Japan signed in 1993 and ratified it in 1995.

The Chemical Weapons Convention stipulates that:

- the states parties shall not develop, produce, acquire, retain, transfer, or use chemical weapons;
- the states parties shall declare chemical weapons to retain and the production facilities of the chemical weapons and, in principle, destroy them within 10 years after the convention comes into force (by April 2007, at the time of entry into force);
- the organization for the prohibition of chemical weapons (OPCW) shall be established as an organization to verify compliance with the convention through inspections, etc., in response to reports from states parties. [1)]

1.3 Stockpile vs. non-stockpile

Chemical weapons that are stocked without being used are called "stockpile chemical weapons." After the entry into force of the Chemical Weapons Convention, the destruction of stockpile chemical weapons has been promoted by the states parties to it that retained chemical weapons. To date, approximately 72,000 tonnes of chemical agents have been declared to OPCW worldwide, of which approximately 70,000 tonnes (more than 97%) have been destroyed.

On the other hand, chemical weapons other than those stockpiled, e.g., munitions that were dumped underground or underwater and unexploded munitions, are called non-stockpile chemical weapons. Many non-stockpile chemical weapons remain unrevealed, making it hard to progress with their destruction.

1.4 Old chemical weapons and abandoned chemical weapons

The Chemical Weapons Convention also stipulates that the states parties shall destroy old chemical weapons in their own countries and chemical weapons abandoned in the territory of other states parties (hereinafter referred to as "abandoned chemical weapons").

Fig. 1 Examples of old chemical weapons

Old chemical weapons are defined as those produced before 1925, or those produced between 1925 and 1946 that have deteriorated to such an extent that they can no longer be used as chemical weapons.[1)] Corresponding to this are the chemical weapons used by the old Japanese armed forces, found in Japan, and the chemical weapons used during World War I and found in Belgium and France (**Fig. 1**).

Abandoned chemical weapons are defined as chemical weapons abandoned by a state after January 1st, 1925 in the territory of another state without the consent of the latter.[1)] The chemical weapons used by the old Japanese armed forces and found in China correspond to this.

These old or abandoned chemical weapons are most often found as non-stockpile weapons.

2. Treatment of chemical weapons

2.1 Various treatment methods

In the past, when chemical weapons that had become unexploded munitions, weapons of defeated nations and the like were to be destroyed, they were often dumped in the ocean. However, with the international ban on marine dumping, as well as the Chemical Weapons Convention having entered into force, the nations that retain large amounts of stockpiled chemical weapons are obliged to destroy them in a short period of time and, as a result, various methods of destruction have been developed. The main ones include neutralization, incineration, and detonation.

The neutralization is a treatment method in which chemical agents of chemical weapons are mixed with reagents in a reactor so as to be decomposed by chemical reactions. Incineration is a method for decomposing chemical agents by burning them in high-temperature incineration furnaces. These two methods are suitable for the mass treatment of each chemical agent alone. Hence, they have been used in many countries to destroy stockpiled chemical agents stored in tanks and the like. In the United States, mass incineration treatments with liquid incinerators have been carried out at most facilities treating chemical weapons since 1990. Recently, Syrian chemical weapons have been neutralized on board a U.S. vessel on the Mediterranean Sea. Kobe Steel also has experience in neutralizing chemical agents left by the old Japanese armed forces at Lake Kussharo, Hokkaido (2000) and Samukawa, Kanagawa Prefecture (2004).

On the other hand, dismantling chemical projectiles, bombs, etc., to separate chemical agents from explosives for individual treatment carries the double risk of exposure to the chemical agents and detonations of the explosives. Furthermore, non-stockpiled chemical weapons left under the ground or in the ocean for a long period of time are difficult to dismantle because of changes such as the corrosion and deformation of the projectiles.

2.2 Detonation treatment

The detonation treatment, in which munitions are detonated to destroy any chemical agent and explosives contained therein, is suitable for treating non-stockpiled chemical munitions such as old or abandoned chemical weapons.

There are two types of detonation treatments, i.e., static detonation and controlled detonation. In static detonation, chemical munitions are heated in a detonation chamber, in which the chemical agents are pyrolyzed. Furthermore, the explosives, such as the burster, are ignited and exploded, and the pyrolysis gas, released from the munitions shell, and the vapor of undecomposed chemical agents are decomposed and removed by a gas treatment device such as a secondary combustion furnace in the subsequent stage. The detonation chamber is always in communication with the subsequent gas treating device and, therefore, there are stringent restrictions on the amount of explosive in chemical ammunition that can be charged at one time, due to the explosion resistance performance. On the other hand, this method is suitable for the mass treatment of relatively small munitions because the throughput can be increased by increasing the charging frequency of the munitions.

In controlled detonation, donor charges are attached to each piece of chemical ammunition, which is subjected to detonation blasting in a sealed explosion-resistant steel container (detonation chamber) so as to destroy the energetic materials and chemical agents. The treatment in a chamber with high explosion resistance offers advantages including the fact that large-sized munitions can be treated, and that the batch treatment facilitates the checking of the destruction of each piece of chemical ammunition and there are measures for dealing with any abnormality that may occur. In addition, by increasing the size and strength of the detonation chamber, the explosive quantity that can be treated at one time can be increased so as to treat a large amount of munitions.

Kobe Steel had the experience, in 2000, at Lake Kussharo, of cutting a chemical bomb, neutralizing its chemical agent, and detonating the energetic materials. After that, the company continued the development of the detonation chamber, etc., applying the manufacturing technology for pressure vessels, and put into practical use the DAVINCH™ system that allows controlled detonation without cutting chemical munitions.

3. Controlled detonation

3.1 DAVINCH™ system

The DAVINCH™ (Detonation of Ammunition in a Vacuum Integrated Chamber) is Kobe Steel's controlled detonation system. Its treatment process is outlined in **Fig. 2** and **Fig. 3**. A donor charge is attached to each piece of chemical ammunition, which is placed in a detonation chamber and the chamber is then depressurized with a vacuum pump. After the addition of an appropriate amount of oxygen, the valve is closed to completely seal the chamber. Subsequently, the donor charge is initiated by remote control so as to detonate the chemical munitions. The sealed detonation chamber contains the pressure of the explosion and the generated gas, and even if the undecomposed chemical agent remains, it will not leak to the environment. The detonation under reduced pressure alleviates the impact load on the detonation chamber and extends its fatigue life, while decreasing noise and vibration.

After the detonation, detonation product gas (offgas) containing a high concentration of hydrogen and carbon monoxide, as well as solid residue, such as shell fragments and dust, remains in the detonation chamber. Then, the valve in the pipe connecting the detonation chamber and the offgas treatment system is opened, and the offgas is sent from the detonation chamber to the offgas treatment system by a vacuum pump. The offgas treatment system not only removes dust in the offgas, but also oxidizes the above-mentioned

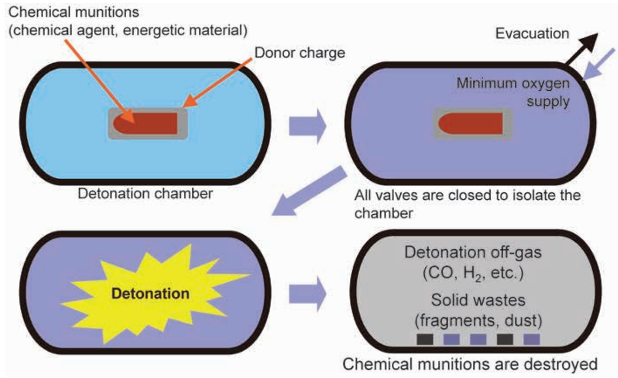

Fig. 2 Destruction process of DAVINCH™ system-(1): detonation

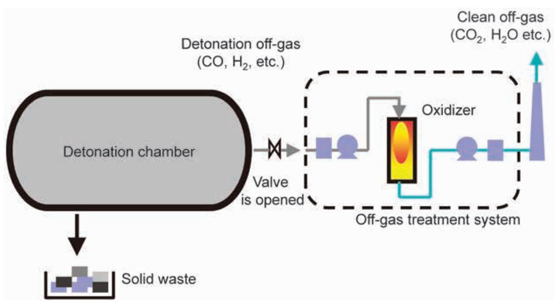

Fig. 3 Destruction process of DAVINCH™ system-(2): off-gas treatment

combustible components such as hydrogen and carbon monoxide. Furthermore, it removes acid gas and the like to convert the gas into harmless treated waste gas containing carbon dioxide, water vapor, nitrogen, etc., and releases the gas into the atmosphere through an activated carbon filter in case a trace of the chemical agent still remains.

3.2 Destruction of chemical munitions by detonation

The pressure and temperature generated by the detonation of explosives reach several GPa and several thousand K, respectively, in an extremely short period of time. When the donor charge is initiated, the shock wave generated by the detonation propagates to the chemical agent inside the chemical munitions through the munitions shell, and some of the chemical bonds of the chemical agent molecule are broken by the shock wave.[2)] Soon, tens to hundreds of micro-seconds after the detonation, the shell of the chemical munitions is fragmented, and when it comes into contact with the products of detonation at high temperature and high pressure, the chemical agents undergo various chemical reactions. Furthermore, they are decomposed almost completely by pyrolysis and reaction with oxygen in the atmosphere at a high temperature, the atmosphere lasting for a longer period of time (approximately 1 second).

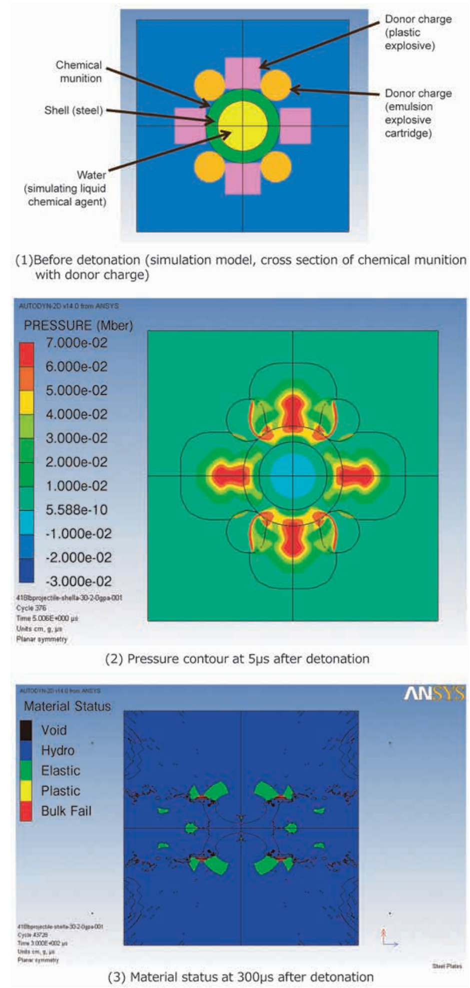

Fig. 4 Numerical simulation of behavior of a piece of chemical ammunition in destruction by detonation

Numerical analysis was performed on the behavior of a piece of chemical ammunition during detonation treatment. An example is shown in **Fig. 4**. Fig. 4 (1) depicts the simulation model. This figure shows the state in which a plastic explosive and a cartridge-filled emulsion explosive are attached as donor charges to the chemical munitions before detonation. Fig. 4 (2) shows the pressure contour diagram of the cross section of the piece of ammunition approximately 5 μs after the initiation of the donor charges, and it can be seen that the shock wave propagates in the munitions shell. The munitions shell is scattered in pieces 300 μs after the ignition (Fig. 4 (3)).

The burster is also initiated by the shock wave transmitted through the munitions shell and is consumed. In other words, the detonation using donor charge completes destruction by breaking chemical munitions, while detoxifying the chemical agents and explosives that have been the sources of danger.

Fig. 5 Detonation chamber delivered to Poelkapelle, Belgium

3.3 Detonation chamber

Fig. 5 shows an example of the detonation chamber. A detonation chamber is a steel container with hemispherical or semi-elliptical heads attached to the both ends of a cylindrical shell, in which one end of the container opens as a lid. The lid and body are sealed by fastening the flanges with hydraulically driven clamps. The detonation chamber has a double shell structure, in which the inner chamber protects the outer chamber from the fragments of the munitions shell that scatter during detonation, and the outer chamber has the role of containing the detonation pressure and gas. The inner chamber is replaced when the damage caused by the fragments exceeds its limit. The outer chamber is used while its remaining life is predicted by the monitoring of fatigue damage through the measurement of strain during detonation.

4. Achievements of controlled detonation by DAVINCH™ system

4.1 Port of Kanda

Chemical munitions of the old Japanese armed forces during World War II, filled with aka (red) agent and kii (yellow) agent, were found on the seabed of the port of Kanda in Fukuoka prefecture. In response, Kobe Steel lifted and recovered about 3,000 of these chemical munitions from 2004 to 2013 and destroyed them with the DAVINCH™ system. In 2017, another object suspected of being chemical ammunition was discovered in the same area again, and Kobe Steel also lifted and recovered and destroyed it from 2018 to early 2019 with the DAVINCH™ system.

4.2 Belgium

In Belgium, which was a site of fierce battles during World War I, more than 200 tonnes of unexploded munitions are still discovered and recovered every year, about 5% of which are chemical munitions. The Belgian Ministry of Defense dismantled the chemical munitions for treatment but decided to use the DAVINCH™ system for the treatment of munitions that are difficult to dismantle.

Kobe Steel delivered the DAVINCH™ facility to the Belgian military base in Poelkapelle in the western part of the country (Fig. 5), and in 2008, the Belgian force began destruction using the facility. By the end of 2018, they had destroyed a total of about 13,700 munitions including approximately 4,400 chemical munitions, mainly filled with DC or DA, and 9,300 conventional munitions which include smoke agent containing arsenic compounds. The destruction is still ongoing.

4.3 France

In France, where many unexploded munitions of World War I are found, as in the case of Belgium, the Ministry of Defense is proceeding with a project, named SECOIA, using a facility for the destruction of old chemical weapons at the Mailly-le-camp military site. The DAVINCH™ system has been adopted in the center of SECOIA facility; Kobe Steel has received an order from the French prime contractor and delivered the system. Currently, the prime contractor is preparing for the start of the destruction operation.

4.4 Destruction of abandoned chemical weapons in China

In China, abandoned chemical weapons left by the old Japanese armed forces during World War II have been found in various places, and the Japanese government has been destroying them. Since 2010, Kobe Steel has been conducting destruction in Nanjing, Wuhan, Shijiazhuang, and Harbin using mobile DAVINCH™ systems. In addition, since 2014, treatment has been implemented by a fixed DAVINCH™ system in Haerbaling, Jilin Province, and in the near future, large-scale DAVINCH™ systems will be delivered to accelerate treatment.

Conclusions

Chemical weapons, whose use began about 100 years ago, not only caused inhumane damage during the war, but they are still threatening the lives of the residents and the environment as unexploded munitions, etc., in various places. Under such circumstances, many old or abandoned chemical weapons have been destroyed without accidents in and outside of Japan from 2004 to the present using DAVINCH™ systems developed by Kobe Steel.

Kobe Steel will continue to improve the design of detonation chambers, process, and equipment, while striving to improve the measures for minimizing the risk of leakage and exposure to chemical agents and preventing the spread of pollution, thus to improve the safety and efficiency of treatment.

References

1) Chemical weapons convention. September 27 2005.
2) T. Matsunaga et al. 2000 Environmental research in Japan. Ministry of the Environment, 2001, pp.56-1-56-48.