Study on cook-off test of HNS at constant temperatures

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Abstract

In order to obtain the characterization of HNS under cook-off condition, the cook-off tests of 3 sizes of sealed HNS pellets, \(\Phi 3\text{mm} \times 4\text{mm}, \Phi 4\text{mm} \times 5\text{mm}\) and \(\Phi 4\text{mm} \times 6\text{mm}\), were carried out under 4 constant temperatures, 400\(\degree\)C, 350\(\degree\)C, 320\(\degree\)C and 315\(\degree\)C. The reaction responses were determined by the damage or distortion of sample tubes and its vulnerable place. The results show that the reaction temperatures take on the decreasing trend with the increasing of charge weight under the same environment temperature. When the charge weights are the same, with the increasing of environment temperature, the reaction temperatures go down.

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Nomenclature

\begin{itemize}
  \item \(t\) \quad \text{time (s)}
  \item \(T\) \quad \text{temperature (\(\degree\)C)}
  \item EFI \quad \text{exploding foil initiator}
  \item HNS \quad 2,2',4,4',6,6'-hexanitro-stilbene
\end{itemize}

1. Introduction

Exploding foil initiator (EFI) is one of the representatives of the third generation of explosive device. It has been widely used in insensitive munitions with its high intrinsic security. The latest U.S. military standard MIL-DTL-23659F, DETAIL SPECIFICATION: INITIATORS, ELECTRIC, GENERAL DESIGN SPECIFICATION FOR, requires carrying out cook-off test in the design and lot acceptance test of in-line initiators [1]. EFI is mainly used in in-line explosive train. It is required that it shouldn’t explode in heat environment in order to protect the weapon system from deadly threaten [2-3]. So it’s meaningful to carry out the cook-off test of EFI. Reference 3 carried out the cook-off test of EFI under 450\(\degree\)C. The safe charge range was obtained. DU Zhenhua et al. [4-5] carried out the cook-off test of various sizes, sealed and unsealed HNS pellets under 3 heating rates. The characteristic of different sealed condition was researched in cook-off test.

In the battlefield, weapons are usually attacked into fire. EFI then is exposed from room temperature to a much higher temperature. In this paper, a constant temperature heating modes are applied to simulate the condition. The aluminium-made sample tubes with HNS pellets are used to research the cook-off response for EFI’s design and usage.
2. Experiment

2.1. Test devices

The cook-off test devices are designed with temperature controlling device, heating device and data acquisition device. Borrowing the idea of ammunition cook-off devices, at the same time taking the cook-off requirements in American military standard into consideration, also GJB5309-2004 Initiator test methods part 16 and 17, the cook-off devices are designed. The devices are made of two parts: the restriction part and standard block, which are showed in Fig.1. There is outer screw thread on the restriction part. There is a cavum in the middle. One temperature measurement hole and four pressure releasing holes are also on the restriction part. The standard block has internal screw thread accommodating the restriction part.

![Fig. 1 Sketch map of cook-off device for (a) Half section of restriction part and for (b) Standard block.](image)

When carrying out the test, the sample tube should be put into the cavum. The two parts are installed. Then they are put into the explosion can which is finally put into the heating device.

2.2. Test methods

After the heating device is heated to the set temperature, the explosion can with cook-off device is quickly put into the heating device. The temperature progress of the tube surface is recorded. The cook-off tests are carried out under 400°C, 350°C, 320°C and 315°C. When a heating peak is detected, the sound of reaction is heard or the temperature is over 350°C, the test can be stopped.

2.3. Test sample and tubes

The explosive HNS-IV is used to make the explosive pellets whose density is 90%TMD. The weight deviation is below ±0.2mg. Table 1 shows the sizes and charge weights of HNS pellets.

| No. | Size /mm | Weight /mg |
|-----|----------|------------|
| 1   | Ø3×4     | 44.3       |
| 2   | Ø4×5     | 98.4       |
| 3   | Ø4×6     | 118.1      |

The sample tubes are made of aluminium. Two parts of the tube are connected with screw thread. The structure is showed in Fig.2. The surface temperature of the tube is recorded.

![Fig. 2. Pictures of sample tubes.](image)
3. Test results and discussion

The $T$-$t$ curves of 3 sizes HNS pellets are showed from Fig.3 to Fig.5. From these figures, the temperatures of 3 sizes pellets have the similar process. It increases from room temperature. As the heating time increases, the temperature increasing rate goes up. When it comes to the set temperature, the rate decreases. The temperature goes steady.

![Fig.3. $T$-$t$ curves of sample No.1 under 4 constant temperatures.](image1)

![Fig.4. $T$-$t$ curves of sample No.2 under 4 constant temperatures.](image2)

![Fig.5. $T$-$t$ curves of sample No.3 under 4 constant temperatures.](image3)

The conclusion can be also drawn from the figures. As the set temperatures increase, the reaction time becomes shorter and shorter. The reaction time can be divided to two stages. One stage is the time from room temperature to reaction which is called induction period; the other is the time of the sudden temperature increase which is called accelerating period. The induction period is the main part of reaction time, and the accelerating period is only several seconds. The environment temperature strongly affects the induction period [6]. The higher the environment temperature is, the shorter the induction period is.

When the set temperature is $315\, ^\circ \text{C}$ (The steady temperature is $298.6\, ^\circ \text{C}$), the heat peak or sound were not detected after 10 hours of cook-off test of HNS pellet of 98.4mg (The length-diameter ratio is 1.25). The pellet condition after cook-off test is similar to the result of $3.3\, ^\circ \text{C}/\text{h}$ cook-off test [4]. It just thermally decomposes. While the $T$-$t$ curves of 44.3mg (1.33) and 118.1mg (1.5) present weak heat releasing peaks. It indicates that the reaction temperature is related to the length-diameter ratio except for environment temperature [6].

Fig.6 shows the distribution of ignition temperature and time. It can be seen from the figure that the reaction temperature shows a descending trend under the same charge weight as the environment temperature goes down. Under the same environment temperature, as the charge weight increases, the reaction temperature also shows a trend of decreasing. The phenomena are similar to the results of programmed temperature cook-off tests [5].

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The higher the environment temperature is, the closer the reaction time is. When it is $400\, ^\circ \text{C}$, the reaction time of different sizes is quite close; the reaction time is various from each other, when the environment temperature is $320\, ^\circ \text{C}$.

The thermal explosion theory shows that the critical ignition temperature of energetic materials is related to its own characteristics, such as the radius of explosive pellets, length-diameter ratio, chemistry thermodynamic and kinetics parameters. When the material and size of the explosive are fixed, the critical ignition temperature is fixed. As for the fixed size of HNS pellets, the critical ignition temperatures are fixed. The reaction time goes down as the environment temperature increases. So, the test results are in accordance with thermal explosion theory. While the reaction temperatures
are not identical, except for the measurement error, the different test methods cause the different heat accumulation. For example, though the sample is quickly put into the heating device, the temperature can be affected by the movement. Another example is that the reaction temperature moves to high temperature zone when the environment temperature goes higher. These are all the factors causing the different reaction temperature in a fixed explosive pellet.

Fig. 6. Distribution diagram of reaction time and temperatures.

4. Conclusions

(1) At the same charge weight, the reaction temperature shows a trend of decreasing when the environment temperature goes down.
(2) In the same environment temperature, as the charge weight increases, the reaction temperature goes down.
(3) The reaction time is less affected by the environment temperature, as it goes up.

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