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Critical Ignition Temperature of Fuel-air Explosive

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ABSTRACT

The charge of fuel-air explosive (FAE) warhead usually is solid-liquid mixed fuel. The solid component is aluminium powder. To meet the demand of FAE weapon usage and storage safety, in the mixed-fuel medium, there must be gaps where adiabatic compression occurs during launching overloading of warhead. Adiabatic compression makes the temperature of the medium in the gaps to rise. High temperature can cause explosion of the mixed fuel during launching acceleration of the warhead, which is very dangerous. Because the fuel is a multicomponent mixture, the critical ignition temperature can't be determined only by one component. Through experiment, the critical ignition temperature of the mixed fuel is attained, and the changing regularity of the pressure following the temperature is shown in this paper.

Keywords: Adiabatic compression, critical temperature, fuel, equation of state, fuel-air explosive, FAE, warhead charge, critical ignition temperature, energetic material, mixed fuel

1. INTRODUCTION

The critical ignition temperature of explosives and propellants is an important parameter, and a foundation for its use and storage safety. Pickard[1] discussed the theoretical method of predicting the critical ignition temperature of explosives and propellants, and proposed a computational model of this. But some parameters in the computational model can't be obtained easily for fuel-air explosive (FAE). The critical ignition temperatures of many single-component explosives can be found in some relative documents, but nothing was found for the FAE, which is a multicomponent mixture

The FAE is a new energetic material, which has attracted attention of scientists working in many countries in the past few years. There are differences between the multicomponent mixtures and the traditional solid explosives in physical state and principle of detonation. The FAE device can be classed into two forms based on the detonation process. One of these is the two-event form of the FAE device. For this kind of FAE device, the mixed fuel is first dispersed by the high explosive in the centre burst pipe (Fig. 1), which forms the cloud composed of the fuel and the air. The cloud is then ignited by the second high explosive charge. This is called the two-event form of the FAE device. The other is the one-event form of the FAE device. In this form, the mixed fuel is dispersing as detonating by the high explosive in the centre burst pipe. For one-event FAE device, the fuel is a multicomponent solid-liquid mixture, which must contain sensitive component, because the mixed fuel is detonating when it is being dispersed. So the critical ignition temperature of the mixed fuel is very low. The

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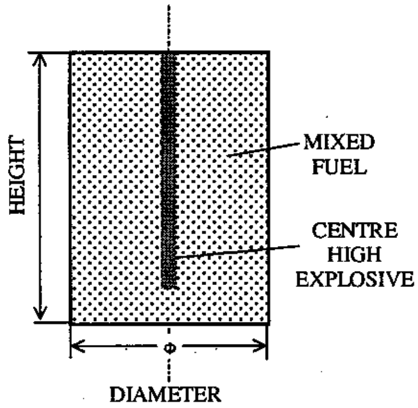

Figure 1. Section of fuel-air explosive device

solid component in the mixed fuel is the aluminum powder. To ensure the stability of the mixed-fuel's physical state, the gaps in the fuel medium are unavoidable. In the launching process, the warhead is pushed by the pressure of the propellant and is accelerated forward. This process is called overloading in launching of the warhead. In the overloading process, the mixed-fuel medium suffers the overload. The stress wave is created in the medium. It starts from the bottom of the warhead and is transmitted to the top. The stress causes adiabatic compression of the gas in the gaps of the mixed-fuel medium, so that the temperature of the mixed-fuel medium rises. The temperature produced by adiabatic compression can be predicted and analysed, while it is difficult to analyse the critical ignition temperature of the mixed fuel theoretically because the fuel is a multicomponent solid-liquid mixture. In this paper,

Figure 2. Accelerating rate calorimeter for measuring and maintaining substantial thermal stability.

the critical ignition temperature of a multicomponent solid-liquid mixed FAE has been tested and studied.

The FAE fuel differs from the traditional solid explosive in that its physical state is sensitive to temperature. Due to temperature rise, parts of the liquid components are vaporised which make the pressure in the shell to increase. So the state equation of the mixed fuel, the relationship between the pressure and the temperature, is the foundation when designing the FAE warhead. The quantitative relationship between the pressure and the temperature has been attained through experiments.

2. EXPERIMENTAL PRINCIPLE

The adiabatic calorimetric method is used for measuring and analysing substantial thermal stability. The adiabatic calorimeter measures the heat and maintains the minimal heat exchange between the tested simple and the environment. Using this calorimeter, the change in the temperature and the pressure following time, caused by physical and chemical reactions under approximate adiabatic condition, can be obtained. Accelerating rate calorimeter, as shown in the Fig. 2, has been used widely.

Firstly, the accelerating rate calorimeter controller heats the testing system up to an initial temperature by radiative heater, meanwhile the heater in the adiabatic furnace is heated up to the same initial temperature following the temperature of the testing system, subsequently the accelerating rate calorimeter testing system (Fig. 3) comes into the state of dynamic heat balance (wait stage). In the wait stage, the controller maintains the state of temperature balance of the adiabatic furnace by comparing the temperature of the sample with the temperature in the adiabatic furnace. After the temperature balance of the adiabatic furnace is reached, accelerating rate calorimeter control system maintains the temperature of the adiabatic furnace at the initial temperature and monitors the temperature change of the sample testing system by the thermocouple in the sample room. If the temperature rise rate of the sample testing system is greater than the slope sensitivity initialised earlier, the test system will come into the exothermic stage. In the exothermic

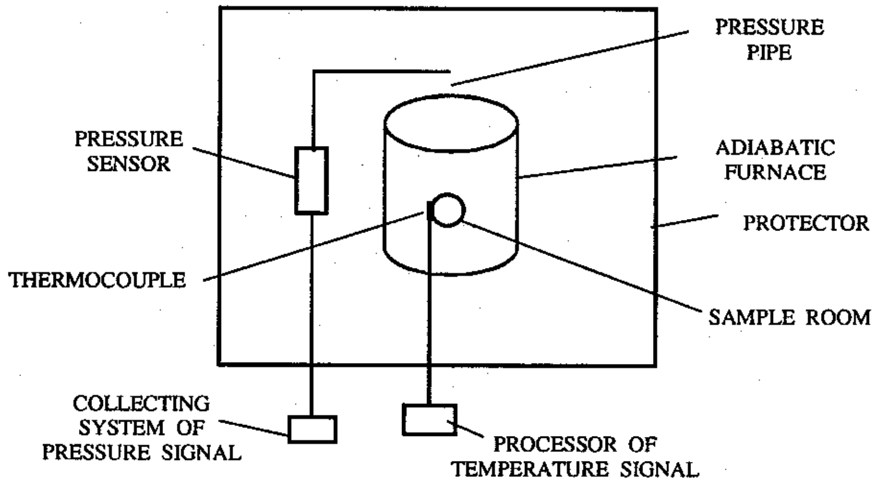

Figure 3. Testing system

stage, accelerating rate calorimeter controller will adjust the heater's power of each district of the adiabatic furnace, according to the temperature difference between the temperature of the sample testing system and the temperature of each district of the adiabatic furnace, to sustain the consistency of the two temperatures and ensure the realisation of the adiabatic condition. If the temperature rise rate is less than the slope sensitivity, the sample testing system will raise the temperature up to a new value (equal to the multiple of the initial temperature and the rising temperature) according to the extent of temperature rise initialised before, which makes the testing system search exothermic action at the higher temperature, or makes it maintain the initial temperature until exothermic action occurs, or comes into the heat-wait-search mode automatically after the isothermal run.

3. EXPERIMENTAL RESULTS

The initial conditions of the experiment are as follows:

Initial pressure = 0.122 MPa

Initial temperature = 50 °C

Sample's quantity = 6.5975 g

Sample room's volume = 5 ml

The critical temperature of the mixed fuel ascertained from the experiment is 207 °C. The pressure of the sample room before explosion of the fuel sample is 3.1 MPa. The change process of temperature and pressure with time is attained (Figs 4 and 5). From 50 °C to 120 °C, the pressure linearly increases with the temperature in the sample

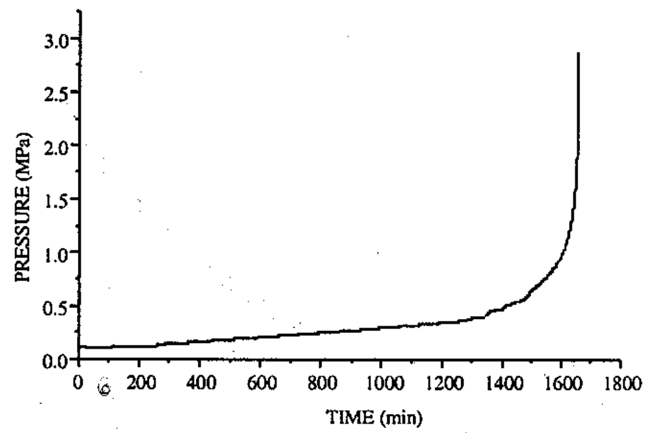

Figure 4. Change process of pressure with time

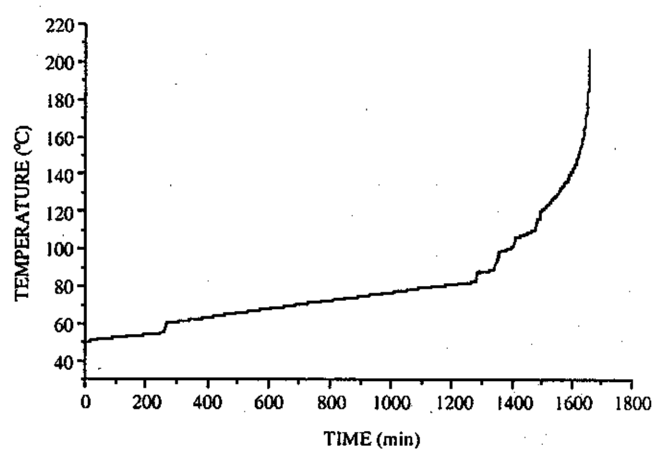

Figure 5. Change process of temperature with time

room, while it increases nonlinearly from 120 °C to 207 °C (Fig. 6). From 180 °C to 207 °C, the temperature rises quickly with time, and at 207 °C, the sample of the mixed fuel detonates. It takes 5 min 30 s for the temperature to rise from 180.76 °C to 207 °C (Fig. 5). From the components of the mixed fuel, aluminum and isopropylnitrate (in 1:1 proportion), it can be seen that certain components begin to combust after attaining a temperature of 181 °C. In the process, combustion of the mixed fuel leads to its detonation.

Through the experiment, the relationship between the pressure and the temperature is obtained (Fig. 6). So the mathematic model can be written as

$$p = -0.3932 + 0.01594T - 1.45178\times10^{-4}T^2 + 6.98314\times10^{-7}T^3 \tag{1}$$

where standard deviation, SD = 0.0176, correlative coefficient R = 0.999, p is the pressure in the

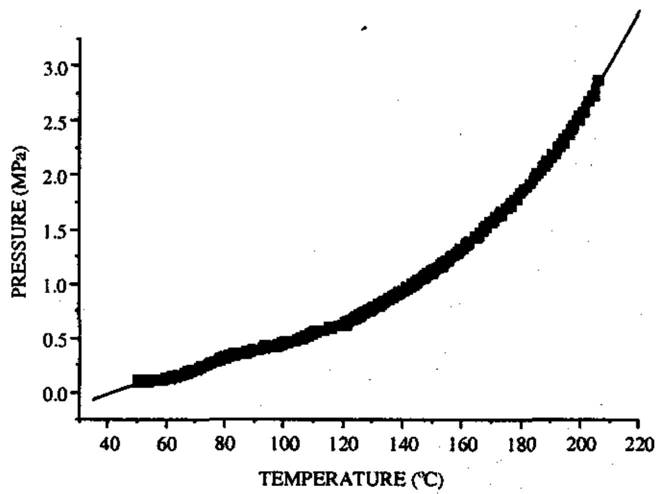

Figure 6. Relationship between pressure and temperature

mixed fuel, and T is the temperature. From Eqn (1), the corresponding pressure can be calculated if the environment temperature of the mixed fuel is known. This is an important problem and must be considered while designing the intensity of the warhead shell.

4. CONCLUSION

The critical ignition temperature of the mixed fuel is an important parameter for its use, storage,

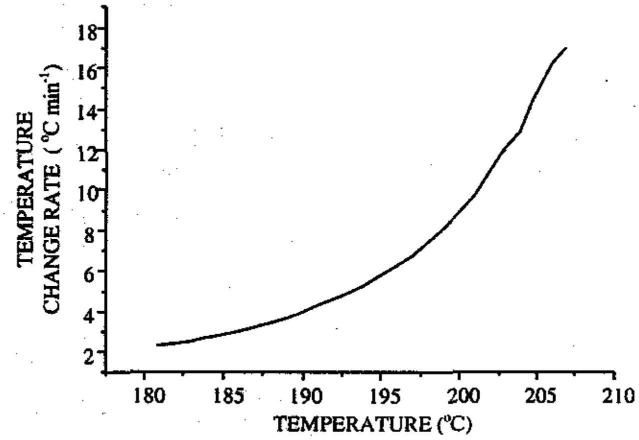

Figure 7. Rate of temperature change versus temperature

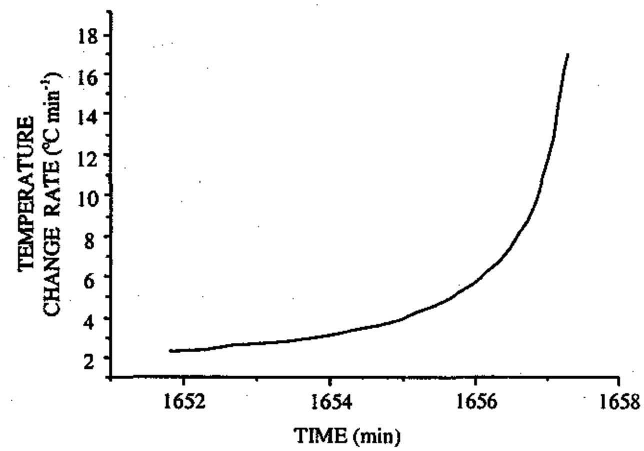

Figure 8. Rate of temperature change versus time

and transportation of an FAE weapon. The mixed fuel is solid-liquid multicomponent mixture. In this paper, the critical ignition temperature of a high energy mixed fuel is obtained and the change regularity of the pressure following the temperature is shown. The critical ignition temperature of this mixed fuel is about 207 °C, and the time taken from combustion to detonation for the mixed fuel is 5 min 30 s.

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