The Simulation of Propellant Fragmentation under Different Temperature

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Abstract. The cold brittleness of propellant at the low temperature is the main cause of the large amount of fraction when launching and easily leads to safety accident. The discrete element method is described in this paper. The propellant particle in the charge is discretized into a multi-body system which consists of many rigidity balls connected with many springs. Combining with the mechanical parameter through mechanical tests at low temperature (-40℃) and normal atmospheric temperature (20℃) of propellant, the process of compress and fracture of gun propellant is simulated at low temperature and normal atmospheric temperature. The simulation results are similar to the test results. It is proved that when at low temperatures, the propellant charge is easily to be fractured and leads to safety accident.

Introduction

The launch situation of modern high performance gun is very bad, and the launch safety became a bottleneck restricting the development of artillery weapons. Large numbers of theoretical, calculation and experimental researches about the propellant launch safety, especially for the propellant mechanics and the fracture rules have been done at home and abroad, including replicating the dynamic compression process and fracture rules of propellant charge by the propellant charge dynamic compression and fracture test device and presenting the fracture degree of propellant charge so as to obtain the surface area of the compression and fractured propellant charge accuracy by initial dynamic vivacity ratio[1], testing the stress-strain relationships of propellant under different temperature and different strain rate by the dropping hammer device and Hydraulic servo stress relaxation tester so as to achieve the mechanical characteristic parameters when the propellant is broken[2-4], analyzing the fracture mode of propellant grain under the impact load by finite element method[5], simulating the shock process of the front and side collision of a single particle by finite element method, which shows the deformation during the collision process of propellant particle vividly[6], and researching the compress and fracture process of propellant bed by the granular fracture dynamics so as to calculate the surface of broken propellant bed [7].

The discrete element method [8] is used in this paper. The dense accumulation propellant charge is discretized into spring - sphere unit system, and the simulation parameters are obtained by dynamic mechanical properties test. Based on the spring-sphere fracture model and the Mohr Coulomb failure criterion, the propellant bed compress and fracture dynamics at normal atmospheric temperature and low temperature is simulated.

Discrete Element Model of the Propellant Particle

The propellant grain is discretized into a system comprised of many spring-sphere units. Two adjacent spheres are connected by 1 normal spring and 2 tangential springs. The sphere unit is the smallest unit. The damage of the propellant is presented by the spring’s deformation and broken. As shown in Fig. 1, each discrete sphere unit is surrounded by 26 sphere units.

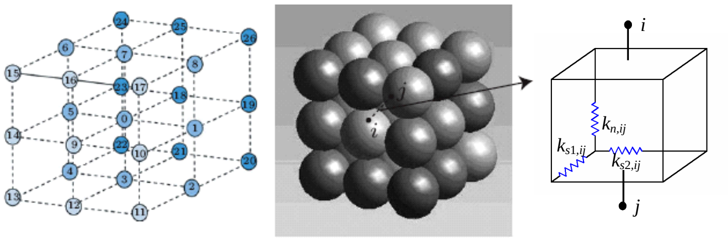

Figure 1. Sphere -spring unit

The coefficients of all spring can be got. The expression is [9, 10]:

$$k_{\rm n}^{1}=k_{\rm n}^{3}=k_{\rm n}^{5}=k_{\rm n}^{7}=k_{\rm n}^{9}=k_{\rm n}^{18}=\frac{2Er(1-v)}{3(1+v)(1-2v)} \tag{1}$$

$$\begin{aligned}&k_{\rm n}^{2}=k_{\rm n}^{4}=k_{\rm n}^{6}=k_{\rm n}^{8}=k_{\rm n}^{10}=k_{\rm n}^{12}=k_{\rm n}^{14}=k_{\rm n}^{16}=k_{\rm n}^{19}\\&=k_{\rm n}^{21}=k_{\rm n}^{23}=k_{\rm n}^{25}=\frac{2Er(1+2v)}{3(1+v)(1\quad 2v)}\end{aligned} \tag{2}$$

$$\begin{aligned}&k_{\rm s1}^{1}=k_{\rm s1}^{3}=k_{\rm s1}^{5}=k_{\rm s1}^{7}=k_{\rm s1}^{9}=k_{\rm s1}^{18}=k_{\rm s2}^{1}=k_{\rm s2}^{3}=k_{\rm s2}^{5}=k_{\rm s2}^{7}=k_{\rm s2}^{9}=k_{\rm s2}^{18}=k_{\rm s1}^{2}\\&=k_{\rm s1}^{4}=k_{\rm s1}^{6}=k_{\rm s1}^{8}=k_{\rm s1}^{10}=k_{\rm s1}^{12}=k_{\rm s1}^{14}=k_{\rm s1}^{16}=k_{\rm s1}^{19}=k_{\rm s1}^{21}=k_{\rm s1}^{23}=k_{\rm s1}^{25}=k_{\rm s2}^{2}=k_{\rm s2}^{4}\\&=k_{\rm s2}^{6}=k_{\rm s2}^{8}=k_{\rm s2}^{10}=k_{\rm s2}^{12}=k_{\rm s2}^{14}=k_{\rm s2}^{16}=k_{\rm s2}^{19}=k_{\rm s2}^{21}=k_{\rm s2}^{23}=k_{\rm s2}^{25}=\frac{2Er(1\quad 4v)}{3(1+v)(1\quad 2v)}\end{aligned} \tag{3}$$

$$\begin{aligned}&k_{\rm n}^{11}=k_{\rm n}^{13}=k_{\rm n}^{15}=k_{\rm n}^{17}=k_{\rm n}^{20}=k_{\rm n}^{22}=k_{\rm n}^{24}=k_{\rm n}^{26}=k_{\rm s1}^{11}=k_{\rm s1}^{13}=k_{\rm s1}^{15}=k_{\rm s1}^{17}=k_{\rm s1}^{20}\\&=k_{\rm s1}^{22}=k_{\rm s1}^{24}=k_{\rm s1}^{26}=k_{\rm s2}^{11}=k_{\rm s2}^{13}=k_{\rm s2}^{15}=k_{\rm s2}^{17}=k_{\rm s2}^{20}=k_{\rm s2}^{22}=k_{\rm s2}^{24}=k_{\rm s2}^{26}=0\end{aligned} \tag{4}$$

In the formula (1) ~ (4), E is the elastic modulus of propellant grain, MPa, and v is the Poisson's ratio.

Getting the Parameters of Propellant Bed

The elastic modulus, Poisson's ratio and compressive strength for propellant grain are needed so as to do the fraction dynamic numerical simulation of propellant charge. According to the reference [11], the Poisson's ratio of the nitroamine propellant particle is $v=0.3$. The elastic modulus of propellant grain can be obtained by the dynamic mechanical properties test, and then the normal stiffness k_n and shear stiffness k_τ are obtained by calculation.

According to the stress-strain experiments, the elastic modulus and compressive strength of propellant grain at room temperature and low temperature are obtained. The elastic modulus of propellant grain at normal atmospheric temperature is $E=722.90$ MPa and the compressive strength is $\sigma_s=64.65$ MPa. The elastic modulus at low temperatures is $E=899.06$ MPa, and the compressive strength is $\sigma_s=87.88$ MPa.

The Numerical Simulation of Compression and Fraction of the Propellant Bed

Considering the accuracy of the calculation and the calculation time, the grains in the propellant bed are discrete into spheres of 0.15mm radius. Then the big grain is discrete into 737 spheres, and the small grain is discrete into 477 spheres. The accumulation state and discrete model of propellant bed is shown in Fig. 2. The pressure curves shown in Fig. 3, as the applied load, load-on the propellant bed. The calculation parameters are shown in Table 1.

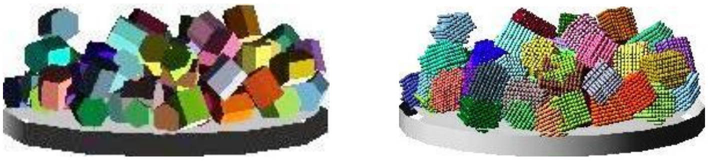

Figure 2. The accumulation state and discrete model of propellant bed

Table 1 The calculation parameters at normal and low temperature

	normal stiffness/Nm^{-1}	tangential stiffness/Nm^{-1}	Time step/s	Poisson's ratio
20℃	7.53×10^{5}	2.15×10^{5}	10^{-7}	0.3
−40℃	9.37×10^{5}	2.68×10^{5}	10^{-7}	0.3

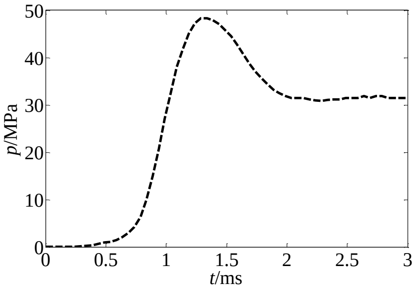

Figure 3. The loading applied on propellant bed

The compress and fracture of the propellant at normal atmospheric temperature and low temperature under the same shock load is calculated. According to the fragment process of propellant bed, the following conclusions can be drawn: the fragmentation of propellant bed at normal atmospheric temperature is not obvious. But the propellant bed at low temperature has a large-scale fragmentation. The surface area numerical simulation results of propellant bed at different times at low temperature and normal atmospheric temperature is shown in Fig. 4.

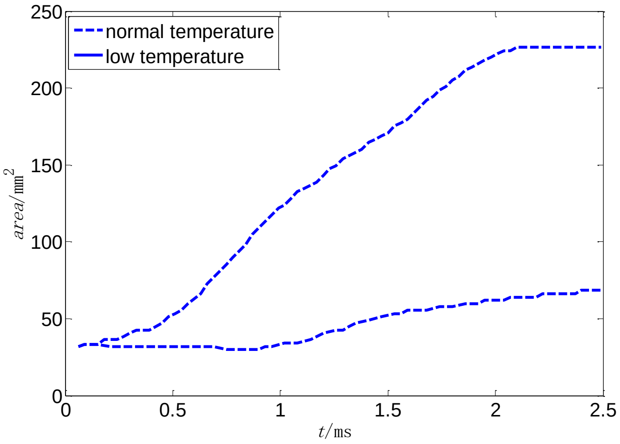

Figure 4. The surface area numerical simulation results of propellant bed at low temperature and normal atmospheric temperature

By the propellant charge initial dynamic vivacity ratio test method in reference [1], the compress and fracture test and the initial dynamic vivacity ratio test for the same quality and same type propellant bed are done and the test pressure curves in closed bomb of fracture propellant are obtained. The test results and simulation results of surface area ratio of the fracture propellant charge and the original propellant charge without fraction under normal atmospheric temperature and low temperature is shown in Table 2. The maximum error is only 3.3% of test and simulation results. The program can simulate the compress and fracture process of propellant charge.

Table 2 The comparison of simulation and test results for the surface area change of fracture propellant charge at different temperature

temperature	simulation	test	error
20℃	1.091	1.082	0.8%
-40℃	1.416	1.464	3.3%

Compared with the results of low temperature and normal atmospheric temperature, the surface area of propellant bed is about 1.416 times before fraction at low temperature. However, the surface area of propellant bed is only 1.091 times before fraction. It means at low temperature, propellant bed is easily broken on a larger scale, which results in the increase of surface area of propellant bed and the unguaranteed launch safety.

Conclusions

The discrete element method is used in this paper. Each propellant particle in the propellant bed is discretized into the spring - sphere system, and the mechanical properties are got by mechanical properties test. The numerical simulation of compress and fracture dynamics process is done when the propellant bed is being launched. The surface area of fracture propellant bed is calculated. The simulation result and the test result is only 3.3% error. This means the simulation has a high reliability. Because the cold brittleness of the propellant charge at low temperature is easy to cause breakage. During the launching, the burning surface area with the corresponding charge structure will increase greatly, which finally results in the chamber expansion, even breech-blow. On the contrast, the propellant charge at normal atmospheric temperature is hardly or rarely broken at the same load. Therefore, the breech-blow generally occurs at low temperature.

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