Simulation of Beryllium Spallation

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Introduction

The paper presents the results of numerical simulation of the series of experiments made at VNIIEF [1] to study the spall fracture in beryllium while loading by non-stationary waves of σ_H = 25-30 GPa amplitude. These waves have been induced to the plane targets due to explosion of HE TNT/RDX 50/50 charge, initiated by a plane wave generator with foam lens. The thickness of the targets and the HE charges were varied in these experiments (Δ_{Be}/Δ_{HE} = 7/7, 7/14, 7/30, 3/7 and 20/100 (mm)). The principal set-up of the tests is similar to that one from [2].

The results of the series of experiments have pointed to the weak dependence of the spall layer thickness on the HE charge thickness. The goal of this work was searching the possible causes of such anomalous dependence for beryllium.

Constitutive Equations

To simulate the beryllium behavior the modified RING model [3], which takes into account the effect of compression and strain strengthening and thermal softening, as well as relaxation of elastic stresses, has been used together with Mie-Gruneisen EOS with variable Gruneisen's coefficient $\Gamma_p=\Gamma_p(\delta)$. The parameters of these constitutive equations for beryllium are presented in [3].

The most perspective approach to simulate the spall fracture among existing ones is kinetic approach and, particularly, the two stage kinetic model of spallation (of NAG type [4]), which is dynamically developed at VNIIEF [5]. The values of six parameters of this model for the beryllium (see Table 1) are based on the experimental results from [6], where the free surface velocity of the plane targets has been recorded in case of low-intensity loading.

σ_{n0}, GPa	σ_{g0}, GPa	σ_1, GPa	$\dot{N}_{00}$, cm$^{-3}\times$s^{-1}	η, Pa$\times$s	R_0, cm
0.95	0.5	0.1	8×10^7	7.0	1.0×10^{-4}

Table 1, Parameters of kinetic model for beryllium

The detonation process in TNT/RDX has been considered using two-phase EOS taking into account the kinetics of detonation evolution.

Numerical Simulation

Experimental free surface velocity of the target W(t) and pressure P(t) in the PTFE base plate are compared with numerical curves in Figure 1.

We consider two possible reasons of overestimating the maximum velocity of free surface in simulations comparing to the experiment. First one is an effect of detonating process evolution in the composite HE used, and second one is possible understating of shear strength of the beryllium in the RING model used.

However, the arrival of the so called "spall pulse" (time moment t_{min} in Figure 1a), which is defined by the spall layer thickness, is quite adequately simulated for three experiments among five done: Δ_{Be}/Δ_{HE} = 7/7, 7/14 and 3/7 (mm). For these tests we obtained the correct simulation of experimental pressure dependences, which were registered by manganin gauge while de-acceleration of the target on the base plate, also: a good agreement between calculation and experiment for both the amplitude and the duration of the P(t) first pulse is seen from Figure 1b.

To exclude the possible effect of detonation kinetics in TNT/RDX 50/50 the specialized experiment has been done, where the beryllium target of 20 mm thickness underwent the contact explosion of TNT/RDX 50/50 charge of 100 mm thickness. Comparison of two W(t) curves shows, that the calculated time of arrival of spall pulse and the spall layer thickness, consequently, exceeds the experimental values more than 5 times.

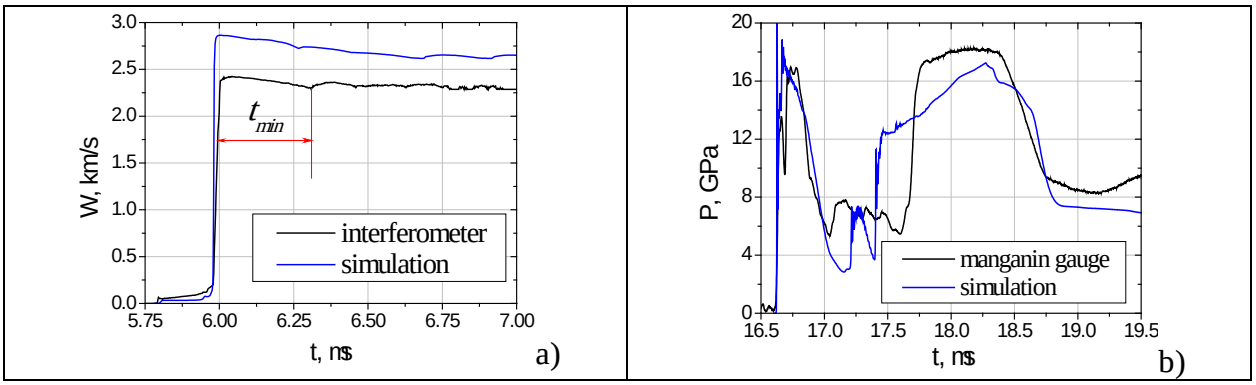

Figure 1, Calculated and experimental [1] curves W(t) and P(t) for test D_{Be}=7mm, D_{HE}=14mm

So, there is correct simulation of spall nucleation in such brittle material as beryllium under explosion of thin charges of HE (~20 mm) and there is a significant discrepancy between numerical and experimental data in case of thick HE charges (>20mm).

As an illustration of this statement the numerical simulation of one of the tests from [2] has been performed. In case of target thickness 5 mm and HE TNT thickness 20 mm there is a quite good reproducing of the spall pulse arrival time at W(t) curve in the calculation, i.e. a quite good description of the spall layer thickness.

Conclusion

The existing experimental data concerning the spall fracture of beryllium under explosive loading cannot be simulated in a single manner by using modern models of high-rate deformation and spallation. The possible ways to search the reasons are: 1) softening of the beryllium behind the shock wave front; 2) change of beryllium deformation character while the strain rate increasing, the so called brittle-to-ductile transition; 3) effect of detonation evolution kinetics in HE charges.

References

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