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NUMERICAL SIMULATION OF FRACTURE: PROBABILISTIC APPROACH

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Summary. *In this paper we consider explosive fragmentation of the open and closed shells, punching of a thick barrier by an shell with charge HE on a normal and at a angle, fragmentation of a barrier and an shell after barrier piercing, undermining charge HE, punching of a thin barrier on a normal and at an angle, crushing of metal rings dressed on a copper tube. All these processes were calculated in view of natural heterogeneity of the material.*

1 INTRODUCTION

The natural heterogeneity of real materials structure influencing distribution of material physicomechanical characteristics is one of the factors determining destruction character. The introduction of the given factor in the equations of a deformable solid mechanics is possible with probabilistic laws of distribution physicomechanical characteristics on a volume of the considered design [1].

There are problems where fragmentation is mainly a probabilistic process: for example, explosive destruction of axisymmetric shells where a character of blasting fragmentation is unknown beforehand. Determining influence of material structure heterogeneity is also evident in the problems of thin barriers punching, in the processes of the so-called barrier "petaling". In order that a simulated process of fragmentation may reflect a real picture of destroyed bodies behavior obtained in the experiments it is necessary to bring in casual distribution of initial deviations of strength properties from rating value to physicomechanical characteristics of the body (modeling of the initial defective structures of the material). In this case destruction process assumes a probabilistic character that corresponds to theoretical representations and experimental data. The introduction of the given factor in the equations of a deformable solid mechanics is possible with probabilistic laws of distribution physicomechanical characteristics on a volume of the considered design.

In work the explosive fragmentation of the open and closed shells, punching a thick barrier by an shell with charge HE on a normal and under a angle, a fragmentation of a barrier and an shell after barrier piercing, punching thin barrier on a normal and under an angle, crushing of metal rings.

2 NUMERICAL PROCEDURE

To describe deformation and crushing of solids we used a model of compressed and perfectly elastoplastic body. The basic equations describing medium motion are based on laws of conservations of mass, impulse and energy and are made by relations Prandtl - Reuses with the Mises flow condition [2-5]. The equation of state was used in the form of Tate and Mie – Gruneisen [2]. Achievement of the limiting value by equivalent plastic deformation or by specific size of work of plastic deformations was used as a criterion of destruction at intensive shear deformations [2,6]. System of equations describes the motion of detonation products (DP) as non-viscous and non-heat-conducting gas. The Landau-Stanyukovich equation was used as an equation of DP state [2].

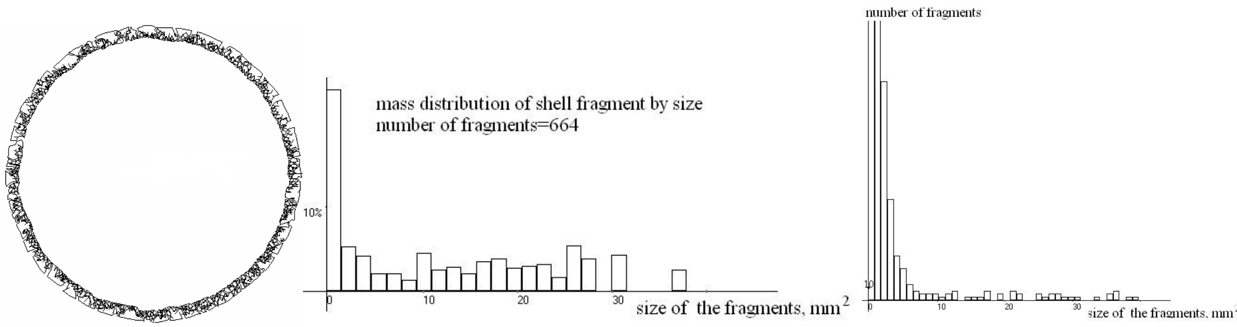
Natural fragmentation of thick-walled elastoplastic shell and barrier was calculated introducing a probabilistic mechanism of distribution of the initial defects of material structure to describe spall and shear cracks. The flaws in the material were simulated varying a limiting value of the equivalent plastic deformation, which was subjected to the normal distribution law with an arithmetical mean, equal to the tabulated value, and by variable dispersion.

For calculation spatial elastoplastic flows and detonation products the technique realized on tetrahedral cells and basing joint application of Wilkins method [3] for calculation of internal points of a body and Johnson method [4,5] for calculation of contact interactions is used. Splitting of three-dimensional area into tetrahedrons occurs to the help of subroutines of automatic construction of a grid.

3 RESULTS AND DISCUSSION

3.1 Blasting fragmentation of shells. Case 2D

In the numerical calculations we used the following characteristics of shell material: (copper) shear modulus = 46 GPa; yield stress = 200 MPa; HE parameters: density = 1650 kg/m^3; D=8310 m/s; inner radius = 2 cm and outer radius = 3 cm.



a b c

Figure 1. 2-D fragmentation of shell: a- shell fragmentation, b- fragments spectrum (total mass – fragment mass), c - fragments spectrum (number of fragments – fragment mass), $t=40\mu s$

3.2 3-D fragmentation of solids

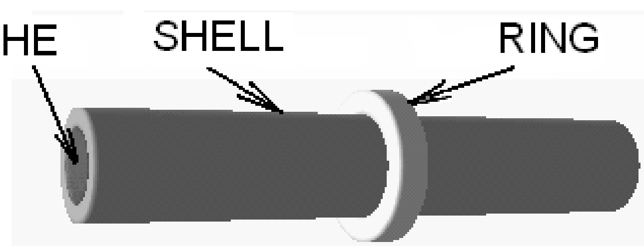
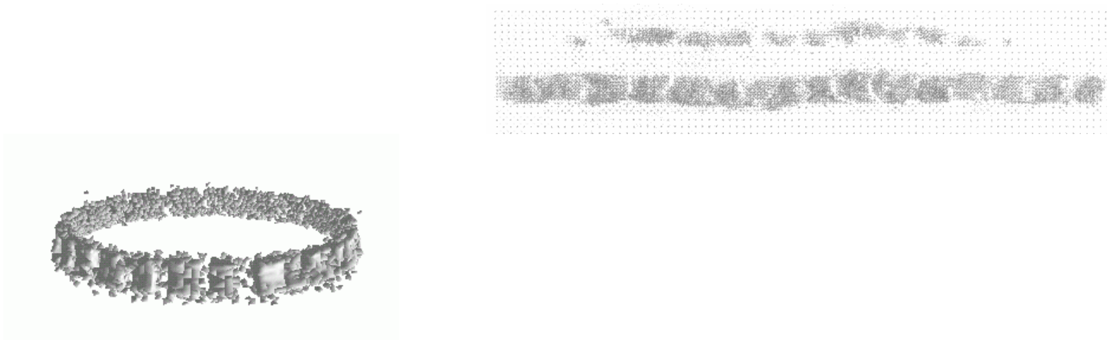


Figure 2. 3-D fragmentation of shell and ring

A copper tube (Figure 2) 20 cm long filled with high explosive. Inner tube radius 1.150 cm, outer radius 1.698 cm. Trinitrotoluene was used as HE. In the middle of the tube a ring was mounted with an inner diameter equal to the diameter of the tube and the outer radius of 2.5 cm. A height of the ring was 1.0 cm. The computational grid used in this calculation was about 500 000 tetrahedral cells. To describe fracture we used the method of bifurcation on knots - at the accomplishment in the neighborhood of the knot fracture criterion (criterion for the equivalent plastic deformation was adopted as such), one observed splitting of knots and the formation of fracture surface. Evolution of the shell and the ring during expansion it presented below in Figure 3 (beginning from 30 ms, detonation products are not shown).

a b

Figure 3. 3-D fragmentation of shell: a -30μs; b - 45μs



a b

Figure 4. 3-D fragmentation of ring: a-calculation; b- experiment [6]

At the solution of the given problem to model the initial heterogeneities we used the following approach – distribution of the limiting value of the equivalent plastic deformation on meshes of the designed area according to normal distribution law with dispersion of 10 per cent deviation

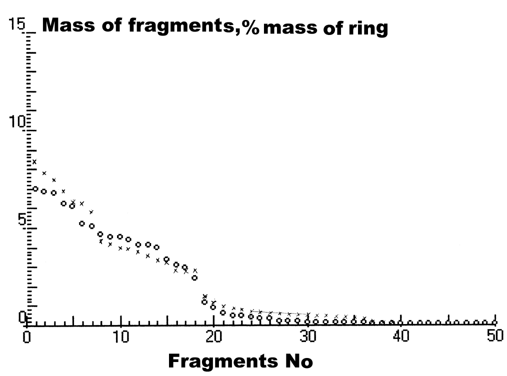
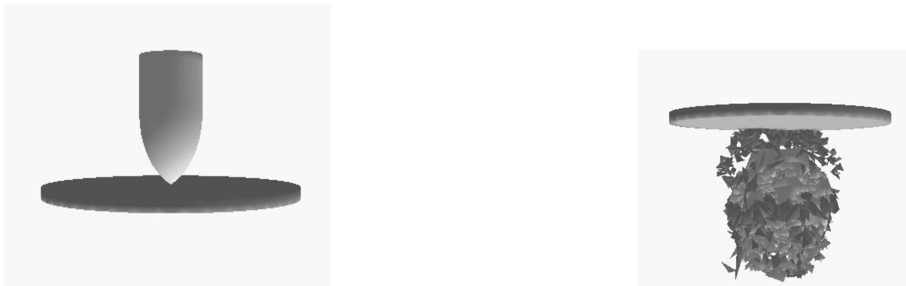
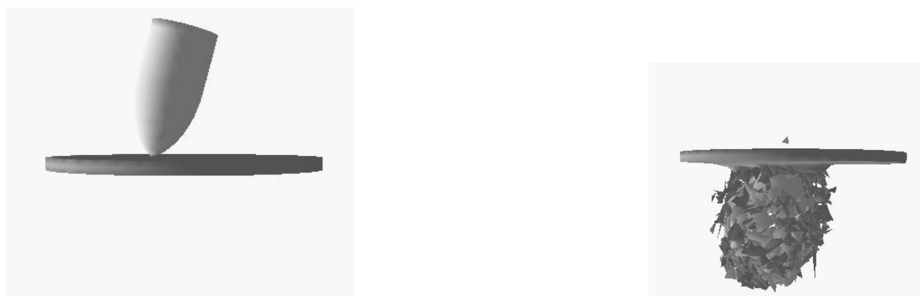


Figure 5. 3-D fragmentation of ring. Fragments spectrum: x- calculation, o - experiment [7]



a **b**

Figure 6. Shell and target interaction at normal impact: a – 0 μs; b – 180 μs



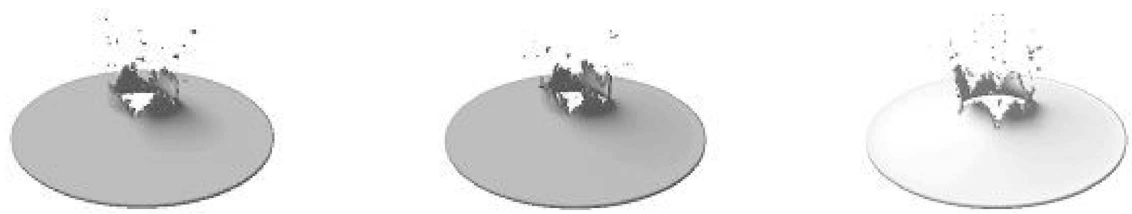
a b

Figure 7. Shell and target interaction at oblique impact: a - 0 μs; b - 163 μs

Target diameter 26.4 cm, width 2.3 mm, strong pinching on edges. Ogival projectile diameter 6.6 cm. The projectile is considered absolutely strong. Velocities: V=150 m/s (copper target), V=300 m/s (copper and steel targets). Fracture measure on maximum strains e_{max}: steel e_{max}= 0.2; yield stress =940 MPa. Copper e_{max}=0.563; yield stress =200 MPa. Visible velocity and plasticity effects Figure 7 and Figure 8 (Cu V=150 m/s - 4 blades , Cu V=300 m/s - 5 blades and St 300 m/s - 6 blades .

a b

Figure 7. Petals formation in copper plate (projectile velocity – 300 m/s):a - t = 200μs;b- t = 400μs.



a b c

Figure 8. Petals formation in copper plate (a, b) and steel plate (c): a-projectile velocity V=150 m/s; b -V = 300 m/s; c - V = 300 m/s

4 CONCLUSIONS

The results obtained indicate possibility of the proposed probabilistic approach and a numerical technique to model process of natural crushing of elements of machine-building designs at intensive dynamic loadings. It is proved by the presented results obtained on solving three-dimensional problems of natural crushing of the closed ogival shells by a running detonation wave, the problems of punching thin-walled barriers by deformable shells without and with fillers. The created technique intended to solve fragmentation problems enables to reproduce adequately crushing of solids at the actions of explosive and shock loadings in the most complete from the physical point of view three-dimensional statement.

5 ACKNOWLEDGEMENTS

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