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Study of ceramic tube fragmentation under shock wave loading

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Abstract

In this paper we investigate the fragmentation of tubular alumina samples under shock-wave loading. Test of tubular samples was performed on a universal experimental set up of electric explosion conductor Bannikova et al. (2013a). The blast tube destroyed into fragments having as rectangular or irregular geometric shapes. The mass distribution obtained by “method of photography” and “method weighting” are in good agreement Bannikova et al. (2013b). For tubes with wall thickness $d = 2.05$ mm formed fragments described of by double distribution: small fragments whose size is much smaller than the thickness of the tube - distribution power law, large fragments described as exponential and logarithmic distribution are equally. The inflection point of the distribution curves moves toward smaller scales with increasing energy density. Besides other determined that Weibull function a good description of the distribution of all the fragments by mass.

Keywords: Fragmentation distribution; electroexplosion; shock wave; alumina ceramic; form factor.

1. Introduction

Still during the Second World War by Professor of Physics N. F. Mott were undertaken the first attempts to describe the statistics of fragmentation objects (cylindrical projectiles) subjected to intensive pulsed load. Grady (2006). Since then, the study of the problems of fragmentation continues by our time, therefore significant experimental and theoretical data accumulated. In the world objects are investigated the dimensions of it varies from laboratory specimens crumbling into fragments of weighing less than a gram to the arctic ice fields photographed by satellite or galaxies crumbling meteorites and asteroids. Studied objects of different shapes – spheres, cubes, plates, rings, rods, and of the most diverse materials – copper, lead, glass, concrete, ceramics, rocks, ice, clay, gypsum, soap, wax, potatoes. The objects are investigated under different loading conditions (impact, creep, bending and compression).

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The main tool of the fragmentation statistical regularities research is determination the fragments distribution by size or masses, in other words, the definition number of fragments $N(r, m)$ with size r or mass m greater than some predetermined. The distribution form depends on many factors: the magnitude of energy expended for the destruction of the sample, the material properties – brittle or ductile, elastic or plastic; dimensionality – 2D for example, plate, rod and 3D – ellipsoid. Depending on the conditions observed distributions of the following types: log-normal, power law (D. L. Turcotte), the distribution of Mott, exponential (D. E. Grady), the Weibull distribution and combination of exponential and power distributions (J. J. Gilvarry).

In this paper we investigate the fragmentation of 2D objects - tubular ceramic samples (alumina), in conditions of the shock-wave loading.

Nomenclature

m_s	mass of sample
d	wall thickness of tube
h	height of tube
r_1	outer radius of tube
r_2	inner radius of tube
ρ_o	density ceramics
W_C	energy stored in the capacitor battery
Q_W	energy expended on evaporation conductor at room temperature
w	density energy of the explosion
N	quantity of the fragments of a given mass
m_f, m	mass of the fragment
d^*	character size of the fragment
S	size of the image area the fragment on photo
S_{in}	the inner surface of the tube, of the fragment
S_{out}	the outer surface of the tube, of the fragment
m^*	mass of fragment by method photography
α	form factor

2. Experiment and materials

Loading of tubular specimens was carried out on a universal experimental setup of electric explosion conductor Bannikova et al. (2013a). Schematic diagram and appearance of the experimental setup are presented in Bannikova et al. (2013a); Bannikova et al. (2013b). It is a complex that includes cylindrical explosion chamber diameter of 0.24 m and a height of 0.085 m, a high voltage source (HVS, U_{max} = 5÷15 kV), storage capacitors system (C_o = 0.022 ÷ 0.44 mF), discharger and discharge ignition system (manual) on the conductor (copper wire diameter d_w = 0.1 mm). Damping material is set on the inner side surface and on the bottom of the cuvette in order to not destroy the wall of the chamber by shock wave. Tubular sample with an axial conductor were placed in the explosion chamber filled with distilled water. The shock wave was initiated in the liquid as a result electric explosion conductor by discharge of the capacitor bank charged from HVS. Water decreased "energy" flying fragments that excluded their further fragmentation by collision fragments with each other and the walls of the chamber. During the tests we performed a series of experiments at different energy of the capacitor bank. Amperage is measured on the conductor with Rogowski coil. The current density was about 10^{11}÷10^{12} A m^{-2}.

Alumina tubes had outer and inner radius r_1 = 5.9 mm, r_2 = 3.9 mm (the thickness of the tube wall d = 2.05 mm) and a height h was in the range 12.7÷16.7 mm (Fig. 1, (a, b)). The density of the tube material was $\rho_o \approx$ 2.6 kg m^{-3}. A result conductor explosion the tube fragmented as show in Fig. 1 (c), they had rectangular and irregular geometric forms Bannikova et al. (2013b).

Optical microscopy showed that the fragments have a developed cracks structure (Fig. 2). Main cracks are vertical gap cracks formed in result a radial loading of explosive wave, and horizontal cracks are on middle of the