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Dynamic fragmentation of shells: scale effects

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Abstract

The effect of the diameter of the shells of structural steel (0.6% C) on the parameters of the cumulative number distribution of fragments by mass and the cumulative mass distribution on fragment length is studied. We tested geometrically similar closed cylinders of different diameters with different wall thicknesses, but maintaining a constant ratio of wall thickness to diameter of the shells equal to 0.175. Detonation velocity and pressure were 8300 m/s and 27 GPa, respectively.

It was found that statistical fragment distributions by mass of the shells of different diameters are well described by the linear exponential relations, and with decreasing shell diameter, indices in these relations equal to reciprocal value of the characteristic mass increases. The diameter of the shell may affect the indices of cumulative mass distributions of fragments along their length described by a power function. With the increase in shell diameter, exponents in these equations are reduced, and the distributions are shifted to a shorter length fragments. These changes in the character and location of distributions are explained by change in the fragmentation mechanism. In the diagram, plotted using of the cumulated mass distributions on the fragment length for shells with different diameters, three parts corresponding to the three regimes of fragmentation is marked out.

The initial stage of fragmentation of shells of small diameter (section I of the mass-fragment length distribution) is connected with the formation of small but numerous fragments limited by initial shear cracks on the inner surface of the shell. In the middle section II, which is linear in double logarithmic coordinates, the main spectrum fragments are formed, and this process develops steadily on the section II a, and with acceleration on the section II b, probably due to the transition from the shear to radial rupture fracture, accompanied by an increase in thickness of the fragments. On the last section III, corresponding to the fragment distribution of shell with the largest diameter, the length of the fragments is growing, but the cumulative mass remains almost constant, that is likely due to the formation of a relatively small number of longitudinal fragments of lesser thickness.

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1. Introduction

Researches on the analysis of scale effects of dynamic fragmentation are few, and they are often contradictory. Thus, the authors Ivanov et al. (1972) and Slate et al. (1967) noted a strong influence of the shell geometry on the fracture mechanism, unlike the authors, Botvina and Odintsov (2006), which found no significant influence of the wall thickness of the shell on the mechanism of dynamic fragmentation of three structural steels. According to study of Slate et al. (1967), increasing the wall thickness of spheres from zinc, copper, aluminum and copper - beryllium alloy leads to a change in ductile fracture by brittle fracture and growth of fracture deformation, which reaches a constant maximum value at the brittle fracture.

Nomenclature

D	outer diameter, mm
d	inner diameter, mm
Δ_0	wall thickness, mm
L	length of shell, mm
l	fragment length, mm
M	mass of shell, g
m_{EC}	mass of explosive charge, g
ψ	reduction of specimen, %
ψ^*	reduction of fragment, %
m	fragment mass, g
m_{EC}	mass of the explosive charge, g
N	number of fragments with the mass larger than m
μ	characteristic mass of fragment distribution

The growth of the strain with the increase in the size of the specimens was observed by Zhang and Ravi-Chandar (2008), who examined regularities of deformation and fragmentation localization of expanding rings made of ductile metals (aluminum and copper) under dynamic loading, and found that with the increase in the absolute size of the specimen and, in particular, with an increase of its cross section, deformation of the beginning of the dynamic localization associated with the formation of the neck increased. According to the authors, this was due to the effects of plastic deformation wave propagation in larger specimens, resulted to an increase in the time before the beginning of the localization process.

At the same time, another researcher, Banks (1968), linked the increase in ductility with increasing duration of action of compressive stresses, inhibiting the development of microcracks. In contrast to this result, Ivanov et al. (1972) showed that the amount of plastic deformation before fracture of geometrically similar shells decreases with increasing size.

These works do not contain systematic information on influence of the material mechanical properties on the manifestation of scale effects, as well as about the changes in the fragment characteristic mass with an increase in the size of the shells assessed by analysis of the statistical distributions of the fragments after the test.

Purpose of work is to clarify these questions by testing geometrically similar cylindrical shells from structural steels with different levels of strength and toughness.