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Experimental and numerical study of peculiarities at high-velocity interaction between a projectile and discrete bumpers

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ABSTRACT

A high-velocity impact interaction of a polyethylene projectile (15 mm diameter) and aluminium projectile (6.35 mm diameter) with string and mesh bumpers (made of steel strings of 0.5–1.0 mm in diameter) was investigated experimentally and numerically. The study was aimed on detecting the projectile fragmentation peculiarities during projectile interaction with discrete bumpers. Since polyethylene has lower penetration resistance than aluminium, the effects inherent to discrete bumper penetration into the projectile must be more obvious for polyethylene. The string bumper is a set of parallel strings lying in a plane. The geometry of the string bumper which is simpler than the geometry of the mesh one also allowed one to get more understandable distribution of fragments on a thick aluminium witness-plate which was imposed behind the studied bumper to register the results of impact interaction for further analysis. The projectile velocity varied in the range of 1.7–3.8 km/s. The geometrical properties of such bumper-projectile system were characterized by two geometrical parameters: the parameter κ characterizing the bumper discreteness and equal to cell aperture-string diameter ratio, and the parameter ε defining the average number of cells falling within the projectile diameter.

According to the experiments, the projectile destruction on string and mesh bumpers is especially distinguished by the accompanying formation of jets of fragments which are ejected from the front part of the projectile along and across its movement direction. The number of the jets correlates with the number of discrete bumper cells arriving at the projectile. The jets intensity depends on the impact velocity and values of the both geometrical parameters κ and ε; the action of the jets on the witness plate (evaluated by the craters depth) can exceed the action of the remaining projectile mass. The numerical modelling evaluates the revealed cumulative effect as follows: the velocity of the fragments in the jets exceeds the original projectile velocity up to factor of ˜1.5 in case when the projectile is aimed towards a cell centre.

The experiments and calculations show that projectile destruction and fragmentation on the string and mesh bumpers are characterized not only by the formation of the jets ejected from the front part of the projectile but also by the shock-wave destruction of rear part of the projectile. The latter is the mechanism, which is inherent to a high-velocity impact on continuous bumpers. Which of these mechanisms prevails depends on the κ and ε parameters values. Frontal fragmentation dominates if the bumper has higher aperture of cells while at lower aperture the part of the projectile mass fragmented due to the formation of the jets diminishes significantly and the shock-wave destruction of projectile prevails. Numerical modelling also explains the mechanism of the formation of craters groups linearly distributed over the witness surface which were observed in the earlier experiments on projectile fragmentation upon the mesh bumpers.

In addition, experiments on the high-velocity interaction of an aluminium projectile with two spaced string bumpers were carried out in case when the aperture of the string cell exceeded the projectile radius. Despite the lower areal density and small inter-bumper distance, the successive string bumpers revealed extremely higher ability to break up the projectile. Intensive fragmentation occurred even in the range of velocities that was lower than a threshold velocity at which the fragmentation of the projectile would have begun on a continuous aluminum bumper with the equal areal density. Numerical modelling makes clear the mechanics of the interaction of the projectile with the spaced string bumpers of the higher aperture.

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1. Introduction

At the present time meteoroid and space debris protection systems of a spacecraft are based on bumper schemes [1]: high impact velocities, which are typical for cosmic space, may provide effective fragmentation of an orbital particle after its encounter with the protective bumper. This decreases the momentum flux density of after-impact residual fragments acting on the rear wall. Hence, the development of valuable and lightweight bumper protection demands additional data on the behaviour of a fragmenting projectile depending on the parameters of the bumper design. The after-impact structure of a debris cloud and distribution of fragments velocities were studied by analyzing the damage of witness plates, X-ray images, and high-velocity video filming [2–7]. The most detailed study of the high-velocity projectile fragmentation on continuous bumpers was fulfilled by Piekutowski [3–5]. Those works thoroughly describe the structure and dynamics of the debris cloud. It was shown that 1) the beginning of the projectile fragmentation has a threshold character under the impact velocity increase; 2) the projectile fragmentation has a shock-wave character and starts with the development of a spall failure its rear part with forming debris cloud around large central fragment. It was mentioned in ref. [4] that the central fragment is the most dangerous regarding the likelihood of the perforation of the rear wall. To improve the bumper a wide set of experiments was conducted [8] in order to undertake the comparative analysis of different (as single, so added together) bumpers ability to affect the projectile fragmentation level. The advantage of the mesh bumper as an element of a multi-bumper protective system was reported in ref. [8,9]. The combination of mesh and continuous bumpers (so called "Mesh Double-Bumper") allowed one to reduce the bumper design weight by ˜30% as compared to a single continuous bumper with the same efficiency [9]. The steel meshes combined with continuous bumpers were used in constructing protective system for the Russian ISS module "Zarya" [10]. A high efficiency of combined mesh bumpers aroused interest to studying the mesh bumper properties. The works [11,12] by Horz et al. are probably the most comprehensive at the moment. In these works the comparative study of high-velocity projectile destruction on mesh and continuous bumpers was fulfilled, and the dispersive and fragmentation properties of a pile of meshes in their interaction with projectile were studied. Horz et al. depicted and described the most vivid distinction in the nature of the projectile fragments distribution at penetration into mesh bumper, namely the presence of crater groups linearly distributed over a witness-plate surface. We obtained the similar result in the experiments on fragmentation of aluminium projectiles on steel meshes [13]. The work [13] also made it clear that the central fragment disruption can be much more effective on the mesh bumper than on continuous one provided some optimal geometrical parameters for the mesh bumper. The theoretical evaluations describing the influence of the mesh parameters on the depth of mesh penetration into projectile were presented in [14].

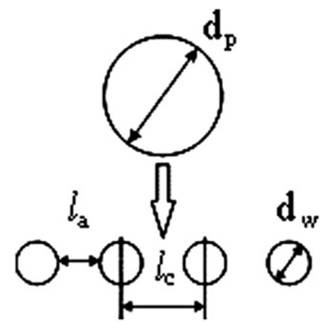

Fig. 2. The parameters of the string bumper and the projectile (side view); d_p – projectile diameter, d_w – wire diameter, l_a – bumper aperture, l_c – cell size ($l_c = l_a + d_w$).

On the whole, contrary to continuous bumpers the mechanics of high-velocity projectile interaction with discrete bumpers was studied quite poorly. The peculiarities of projectile destruction on a discrete bumper were also studied insufficiently. It is probably connected with additional possibilities of the geometrical parameters of such bumpers (string diameter and mesh size) which demand to carry out a larger range of experiments. It is qualitatively clear that destruction of the projectile starts instantly on its frontal surface after its interaction with mesh strings, and the strings penetration depth should define the picture of projectile frontal fragmentation. As a result, the formed debris cloud should look unlike the pattern viewed at projectile interaction with a continuous bumper.

The high-velocity interaction of polyethylene and aluminium projectiles with string and mesh bumpers is investigated in the present work. The study is aimed on experimental and numerical

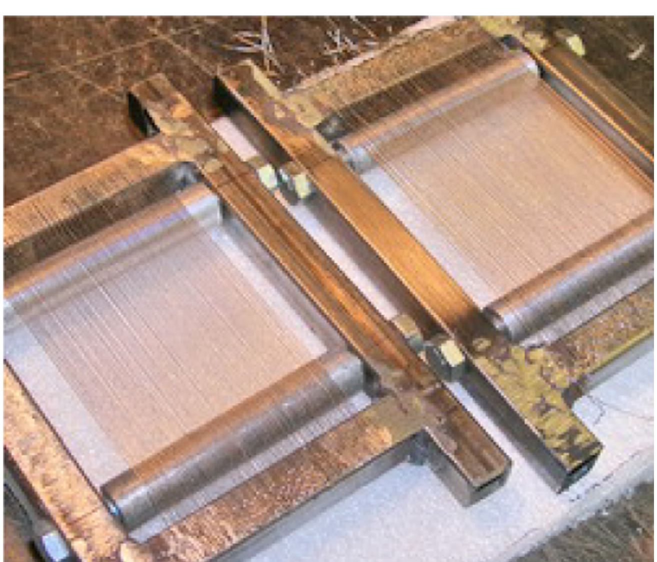

Fig. 1. String bumpers.

Fig. 3. The experimental assembly.