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Complex Research on the Interaction of Glass with Space Debris

Aleksandr V. Gerasimov[1, a)], Mark P. Kalashnikov[2, 3, b)], Victor P. Sergeev[2, 3, c)], and Yurii F. Khristenko[1, d)]

[1] Scientific Research Institute of Applied Mathematics and Mechanics, Tomsk State University, Tomsk, 634050 Russia
[2] Institute of Strength Physics and Materials Science SB RAS, Tomsk, 634055 Russia
[3] National Research Tomsk Polytechnic University, Tomsk, 634050 Russia

[a)] sp@ms.tsc.ru
[b)] kmp1980@mail.ru
[c)] vserg@mail.tomsknet.ru
[d)] Corresponding author: hrs@niipmm.tsu.ru

Abstract. This paper discusses the interactions of barriers with a spherical impactor and the character of possible deformation and fragmentation of barriers and impactors. The destruction of glass is considered as a process of destruction of fragile material without a part of plastic deformation characteristic of the deformation metals. To calculate the elastic-plastic flow a technique was used which was implemented on the tetrahedral cells and based on the combined use of the Wilkins method for calculating the interior points of the body and the Johnson method for calculating contact interactions. Methods for accelerating the flow of fine particles and the individual spherical particles have been developed. A series of experiments for usual glass and glass with coatings has been carried out.

Keywords: space vehicles, debris, grid, high-velocity interaction, probabilistic approach, fragmentation

INTRODUCTION

Ensuring resistance elements of spacecrafts (SC) made of glass is an important practical problem. It is necessary to investigate processes of interaction of glass with flows of man-made and natural debris both from the point of view of preservation of integrity of spacecrafts at an impact with rather large fragments, and to decreasing erosion of the components under the t action of flows of ultrafine particles.

Therefore experimental and theoretical determination of the limit resistance of the elements of the SC design affected by high-speed particles is highly relevant from the practical point of view. An important component of the problem of protection is the problem of obtaining reliable coatings for spacecraft elements from glass [1].

EXPERIMENTAL PROCEDURE

To study the high-speed interaction, an experimental stand, consisting of a universal base frame, on which any available Research Institute of Applied Mathematics and Mechanics of Tomsk State University projective units (T-29, PPH 23/8, 34/8 PPH, PPH 34/23/8, DRO 50/23, etc.) can be installed in and a vacuum chamber were developed put into operation. Some light gas installation (LGI) are shown in Figs. 1 and 2.

The stand is connected to the Measuring Complex (MC) having 6 measuring channels with resolution from 20 ns to 1 ns and a memory capacity from 4 to 32 K on each canal (two-channel digital storage oscillographs GWINSTEK GDS-806C and PCSU1000). All oscilloscopes are connected with the PC, allowing the primary processing of experimental data and their archiving. Variety of research into high-speed impact at speeds up to 8 km/s and higher can be performed.

Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures
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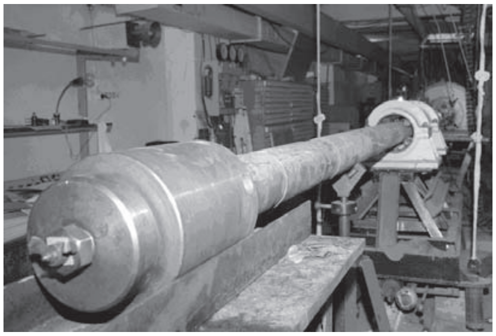


FIGURE 1. LGI with the light piston PPH34/12.7

FIGURE 2. LGI with the heavy piston MPH23/8

Mathematical models of dispersing high-speed particles on the installation and their movement outside the out of installation and their impact with a barrier were developed. A mathematical model of despersing single small-size particles using a two-level light gas installation is suggested (LGI). Processes in this installation are quite complex, so in mathematical modeling only their most essential aspects were taken into account, namely, non-stationary processes and a wide range of changes in the gas temperature, pressure and velocity. Three-dimensional modeling of the interaction of barriers with high-speed strikers is based on equations describing the spatial adiabatic motion of a solid compressible medium, which are differential consequences of the fundamental laws of conservation of mass, impulse and energy [2]. The criterion of the limit equivalent plastic deformation was used as a criterion of the shift destruction. In this case, the calculated cell was considered destroyed when the limit value was reached. The natural fragmentation of impactors and obstacles is calculated by introducing a probabilistic distribution mechanism of the initial defect structure of the material [3].

RESULTS

To calculate the elastic-plastic flow, a technique implemented on the tetrahedral cells and based on the combined use of the Wilkins method [4] for calculation of the internal points of a body and Johnson's method [5] for calculation of the contact interactions is used. The division of a three-dimensional area into tetrahedrons occurs sequentially using subprogrammes of automatic building of a grid. Destruction of glass is considered as a process of destruction of brittle material without plastic of the deformation region characteristic of the deformation of metals. Sensors installed on the LGI fail when 50 μm in size are dispersed so the flow rate was determined using craters' size a barrier. Figure 3 shows the calculated depth values *h* (Fig. 3a) and the diameter *d* (Fig. 3b) for various dispersion rates of crater throwing the steel impactor and the experimental data (Fig. 3c) to determine the dispersion speed in the depth and crater diameter.

The above satisfactory results allowed the use of this approach to determine the rate of 50 μm in size dispersed by the light gas gun (Fig. 4).

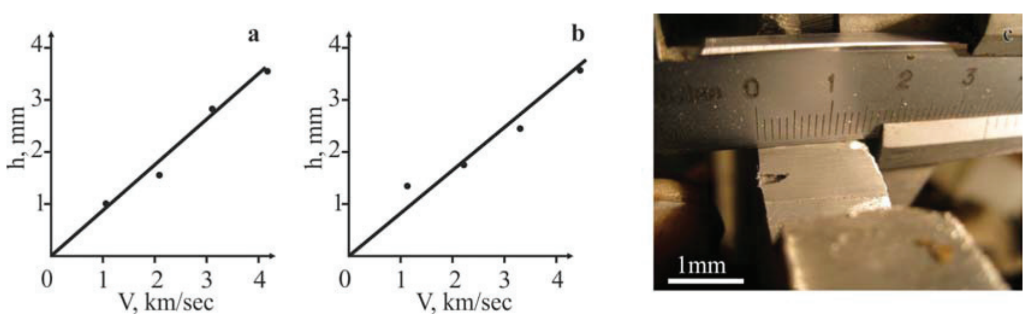


FIGURE 3. Impact of a steel ball 1 mm in diameter with an aluminum plate 6 mm thick and 10 mm in diameter

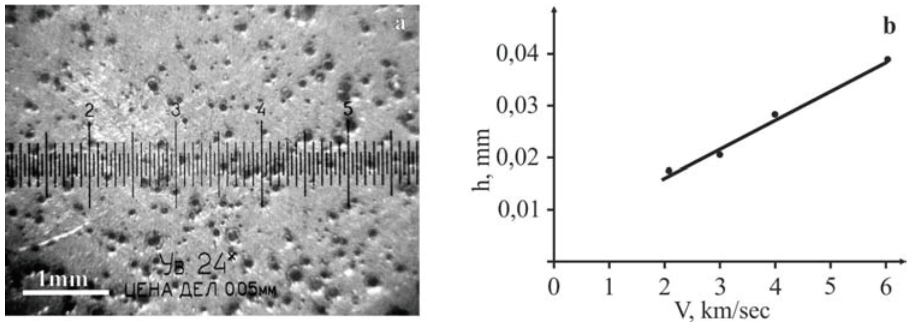


FIGURE 4. Impact of steel particles 50 µm in diameter with an aluminum plate: (a) a photo of the surface of an aluminum plate treated by the flow of high-speed steel particles; (b) the calculated values of the crater depth to an aluminum plate for various rates of the dispersed impactor

The results were used to determine the rate of the clouds of microparticles with the light-gas gun. Figure 5 shows the target device with glass elements to study their interaction with the flow of steel particles (Fig. 5a) and traces of such interactions (Fig. 5b). Numerical modeling of the interaction of a plate from K8 glass with one steel particle (Fig. 6) was carried out. The diameter of the ball was 50 µm, the velocity of impact was 1, 2, 3 km/s.

Figures 6a and 6b show two-dimensional sections of the three-dimensional computational domain for the impact velocity of 3 km/s for the time t = 0.094 ms and the velocity distribution inside the plate and the remains of the ball. The plate is shown in red, the remains of the ball in green, the blue is the micro debris of the interacting bodies. Figure 6c shows the calculated line describing the dependence of the depth of the crater at the impact steel by the ball 50 µm in diameter on a glass plate for a number of speeds of the dispersing impactor. There is a fragile destruction accompanied by the glass and the formation of a cloud of fragments partial the impact of craters.

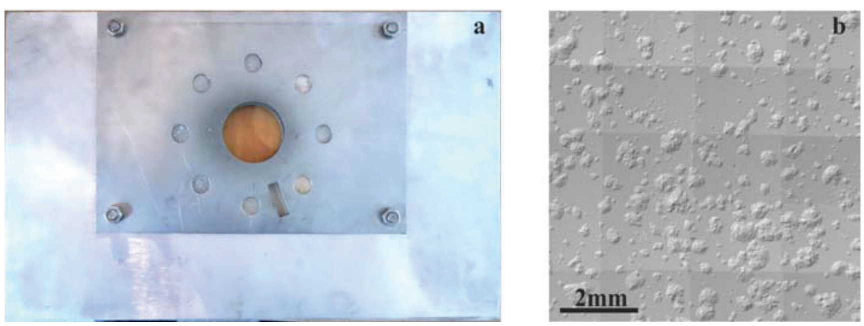


FIGURE 5. The target device (a) and the barrier element surface after an impact by the flow of the particles

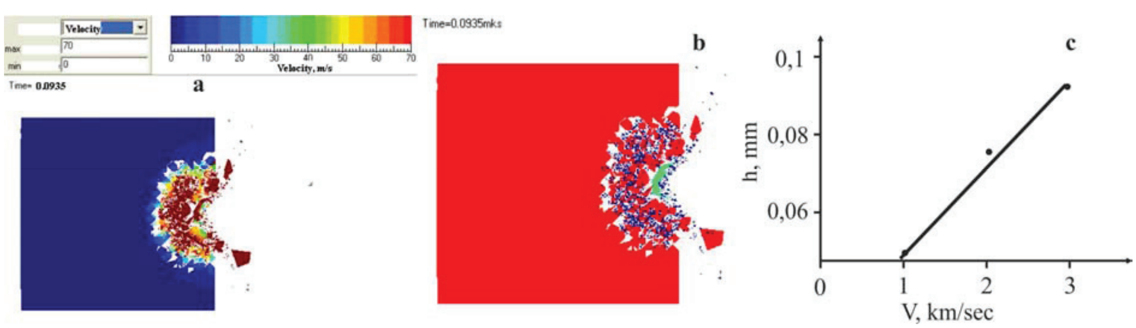
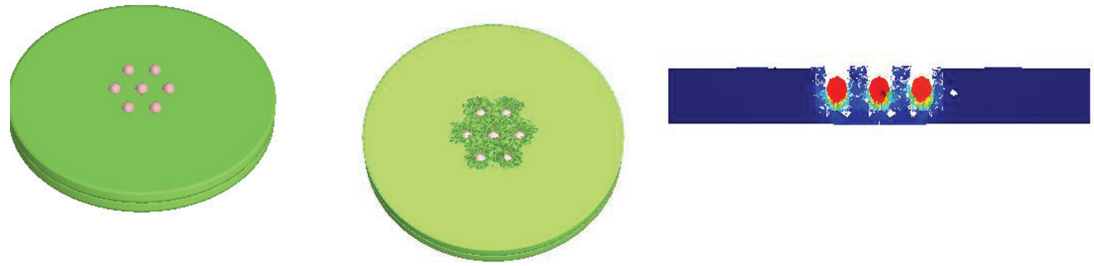


FIGURE 6. Interaction of a glass plate with a steel particle



(a) (b) ©

FIGURE 7. Impact of the group of seven spherical steel particles with the glass surface: (a) calculating scheme; (b) 3D configuration; (c) 2D section of calculated area

The results of modeling of the impact of the group of seven spherical steel particles with a glass surface are given in Fig. 7. The radius of the particles is 0.5mm and they located above circle diameter $D_1 = 4.0$ mm. Glass plates have the diameter $D_2 = 20.0$ mm, and the thickness of plates was $h = 1.0$ mm. The initial speed of the particles was $v = 1.0$ km/s.

The speed and mass of the particles is rather large and there is a breakdown of barriers followed by fragmentation interparticle space.

The proposed approach allows the performance of a comprehensive experimental and theoretical study of the behavior of glass samples in contact with the flow of microparticles, obtaining the parameters of the stress-strain state, determining the nature of the damage and the fragmentation patterns.

ACKNOWLEDGMENTS

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