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Influence of the angle interaction of the projectile with the wire mesh

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Abstract. The problem of interaction of the high-velocity solid spherical shock element simulating a micrometeoroid and the combined protective screen including the mesh barrier is considered. The mesh layer is made of steel wire by weaving method. As a result of numerical modeling by SPH method the results of protective wire mesh and projectile destruction behavior are obtained. The effectiveness of several variants of multilayer screen of equal specific mass with different angles of mesh layer orientation is compared.

1. Introduction

The interaction of high-velocity a micrometeoroid mimic projectiles with protective screens has been a subject of research for quite a long time. Increase of efficiency of antimeteoroid protection of spacecraft is connected with optimal correlation of mass and reliability, as weighting of spacecraft structure, as a rule, is inadmissible because of a number of restrictions, which are laid down during its design.

The use of metal wire mesh as the elements of combined protective screen allowing to reduce the total weight of spacecraft protective shield while maintaining its efficiency looks promising [1]. Special effectiveness is demonstrated by protective screens in the form of corrugated metal mesh, in which the degree of crushing of a projectile can increase more than twice [2], due to the effect “grater” on the inclined wire mesh and increase of interaction time.

The main purpose of this work was to estimate the influence of corrugation mesh angle on the efficiency of conditional corrugated mesh screen [2] at interaction of micrometeoroid with combined protective screen.

2. Mathematical statement

2.1. Mathematical model

Numerical modeling in three-dimensional geometry was performed on the basis of the complete system of equations of mechanics of deformable solids by the method of smoothed-particle hydrodynamics (SPH) using the license package LS-DYNA. The absence of a finite element mesh allows the SPH method to naturally simulate the fragmentation of interacting elements and the motion of the fragments group at a high-velocity impact, and a good correlation with natural tests is noted [3].

In most high-speed experiments, a body made of Al-alloy is used as of a particle acting as a projectile, because it is close in size and density to chondrites, the most common in Earth orbit micrometeoroids.



Therefore, the materials used in this work are aluminum alloy – projectile, one layers of bumper, steel – corrugated metal mesh. To describe the mechanical behavior of the projectile and the wire mesh barrier at high-speed interaction, the Mie–Gruneisen's equation of state as a function of particle velocity $v_s(v_p)$ defines the pressure for compressed materials, and the Johnson–Cook model is taken as the defining relations describing the behavior of an elastoplastic body. The similar model used in this work is found in the works of other authors [4-7]. Verification of the model is confirmed in [8, 9].

The physical-mechanical parameters and strength parameters of the Johnson–Cook model for aluminum alloy and steel used in the calculations are given in table 1; here ρ_0 is the initial density of the material, G is the shear modulus.

Table 1. The mechanical constants of the material.

	ρ_0 (kg/m ³)	G (GPa)	C	S_1	γ_0	a
Projectile, Bumper	2770	27.6	5328	1.338	2	0
Grid	7750	81.8	4569	1.49	2.17	0
	A (Pa)	B (Pa)	C	n	m	T_m (K)
Projectile, Bumper	$3.37 \cdot 10^8$	$3.43 \cdot 10^8$	0.01	0.41	1	603.85°
Grid	$1.54 \cdot 10^9$	$4.77 \cdot 10^8$	0.012	0.18	1	1489.85°

2.2. Geometry of the model

The high-velocity interaction of the projectile with the multilayer spaced barrier (layer of corrugated steel wire mesh and Al bumper) was carried out normally, at different angles of orientation of the wire mesh layer (figure 1).

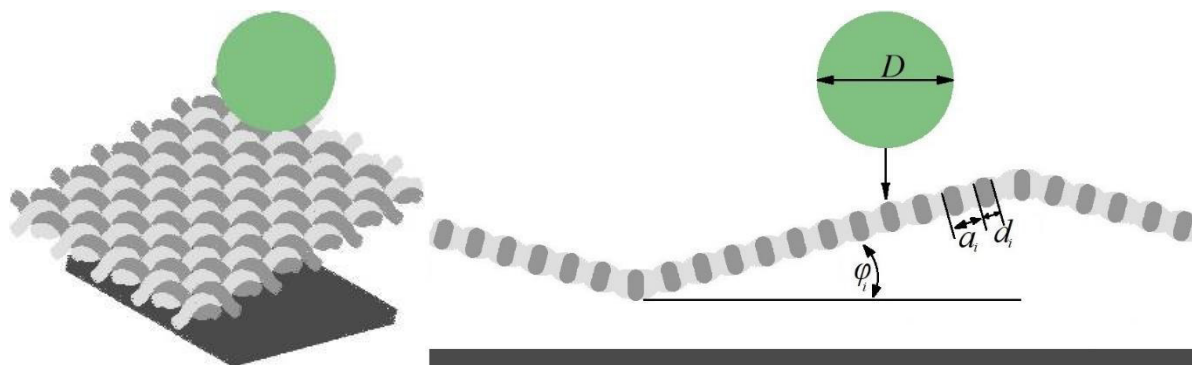


Figure 1. The geometry of the grid and the projectile.

The corrugated mesh layer is modeled by the mesh section at a corresponding slope. At zero corrugation angle φ (angle of mesh layer deviation from the plane of combined protective screen), the corrugated mesh layer is located in the plane of shield. Calculations were made for $\varphi = 15^\circ, 30^\circ, 45^\circ, 60^\circ, 75^\circ$ (table 2).

Table 2. Initial parameters of the model.

D (mm)	a (mm)	d_{15} (mm)	d_{30} (mm)	d_{45} (mm)	d_{60} (mm)	d_{75} (mm)
2.3	0.556	0.244	0.231	0.209	0.175	0.126

Comparison of efficiency of different protective screens makes sense only under condition of their mass coincidence. Therefore, when the corrugation angle (i.e. the angle of mesh inclination) is changed,

the diameter of the wires is recalculated according to the equation in order to preserve the specific density (in the plane of the screen, perpendicular to the direction of impact):

$$d = d_0 \cdot \sqrt{\cos(\varphi)}$$

where φ is the angle between the wire mesh and the horizontal axis, d_0 is the wire diameter at $\varphi = 0^\circ$.

2.3. Boundary condition

To simulate the high-velocity interaction of the projectile with the mesh barrier, the boundary conditions were applied as follows, on the lower (rigid fixation) and upper (movement in the Y axis and free movement in the X and Z axes) boundaries:

$$U_x^{PKLMN} = U_y^{PKLMN} = U_z^{PKLMN} = 0(m)$$

$$V^{proj} = 5000 \left(\frac{m}{s} \right)$$

where $U_{x,y,z}^{PKLMN}$ the rigid closing along the perimeter of the mesh barrier and bumper, V^{proj} the projectile velocity is normal to the bumper, imitating the shell of the spacecraft.

3. Results and discussion

Calculations show (figure 2) that with a small angle of corrugation, the destruction of the projectile starts from its front part immediately after contact and is characterized by the formation of jets (high-velocity fragmentation flow streams) ejected in the direction of impact. The jets formed after the impact are not ejected normally, but disperse at some angle, which in turn will increase the area of impact. This is the main feature of fragmentation when interacting with the wire grid barrier. The number of jets correlates with the number of cells hitting the projectile. The energy of the moving particles is reduced by active mass scattering of the fragments.

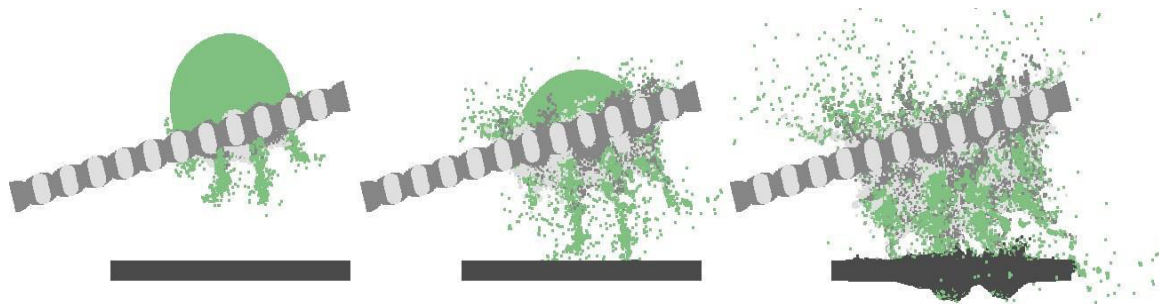


Figure 2. Destruction of projectile before interaction with bumper at $\varphi = 15^\circ$.

As the angle φ increases (figure 3), the jets become less pronounced, the effect of “grater” of the projectile on the wire mesh increases, while the speed of the outgoing jets continues to be predominantly directed along the normal to the mesh bumper. Thus, the most part of the fragment cloud deviates from the impact direction and changes the barrier impulse. This leads to a decrease in the penetration ability of the projectile, in particular, for this task decreases the size of the hole punched in the bumper. Additionally, an increase in the mass of fragments sliding along the mesh layer can be noted, up to the rebound of the unbroken part at large corrugation angles.

Theoretical estimation shows that high-velocity interaction of an aluminum projectile with the corrugated metal mesh as well as with layers of bumpers can lead to sufficient heating to the melting

point. Obviously, in experiments, heating should lead to a sharp drop in the resistance of the projectile material.

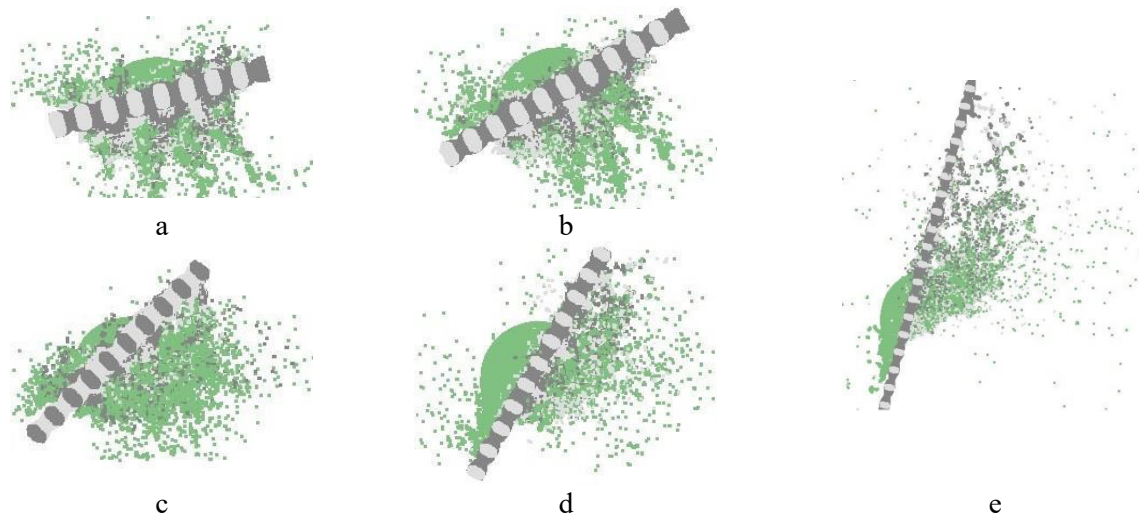


Figure 3. High-speed interaction of the projectile with the wire mesh, a) 15°, b) 30°, c) 55°, d) 60°, e) 75°. Side view.

4. Conclusion

In the work problem of interaction of high-velocity micrometeoroid with the combined protective screen including the layer from the corrugated wire mesh was numerically solved. The mechanism of interaction and destruction of projectile–mesh system at different corrugation angles was investigated. Variability of specific weight of protective screen for different corrugation angles was provided by change of wire diameter of the mesh.

At small angles of deviation from normal interaction, the wire mesh barrier is destroyed as a thin-walled sheet of the continuum material. With an increase in the angle of inclination of the mesh layer, the effect of grater of the projectile against the mesh increases, with the fragmentation cloud shifting away from the impact axis. The share of the projectile that ricochet along the wire mesh also increases, and for smaller projectile it is possible to rebound the undestroyed part of the projectile.

Acknowledgments

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