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THE MECHANICAL ACTION OF POWERFUL ENERGY FLUXES UPON THE HIGHPOROUS HETEROGENEOUS MATERIAL

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The development of new particle boosters requires new models, describing of behavior of powerful beam interaction with heterogeneous insulator materials. The method of thermal properties determination of high porous material, irradiated by powerful electron and X-ray beam was developed. The differential equation of state for porous matter was used. The powerful flux action upon various material types is numerically studied. Calculated data are compared with experimental one.

1. Introduction

The action of powerful energy flux upon condensed matter is a suitable method for the study of thermal characteristics in the broad area of phase diagram. Pulse energy flux action upon heterogeneous porous matter is explored slightly, though shock compression of porous matter is used in the physicist of shock waves for equation of state building. The interest in porous matter is stimulated by their using as protection material for bodies, irradiated by different energy fluxes. At present the one of the most perspective mean of protection is using on surface of irradiated body a bumper shields of heterogeneous material with tungsten covered hollow glass microballoons (GMB) as a filler and rubber as a binder.

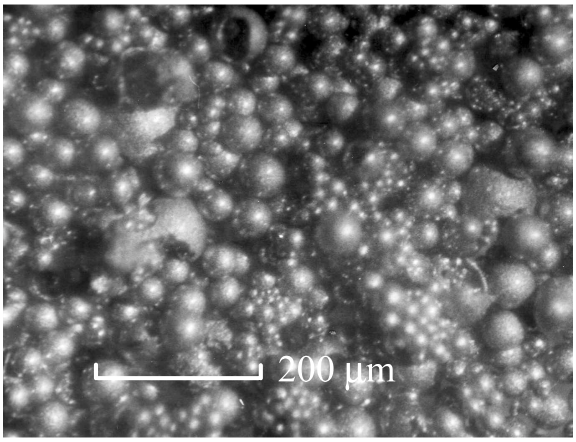

Fig.1. V.P. Efremov, V.E. Fortov et al.

The aim of the paper is the investigation of pulse electron and X-ray beam action upon the perspective composite materials. For the task solution it is necessary to build on the base of experimental data the mathematical model of high porous insulator material, irradiated by powerful energy flux, as well as to determinate numerously and experimentally thermal properties of this material.

The behavior of investigated GMB-rubber material in shock waves generated by powerful pulse is assumed to be complex [1]. Effects that need to be considered include energy deposition, heat transfer, porosity influence, features of fabrication, GMB crushing and size distribution [2]. There are the following phenomena, which are of primary interest:

- initial pressure generation in the GMB filled material;
- pressure evolution and shock wave motion in the material.

2. Mathematical model

2.1 Initial pressure generation

The pulse action of powerful electron beam or X-ray beam on sandwich structure with bumper shield is considered. Irradiated protection material is GMB filled rubber composite material with initial density 0.75 g/cm^3. Initial pressure generation is defined by Gruneisen's factor of material, which depends on material structure. In the model we take into account that two sizes of filler are present – with typical radius R and $R^*=0.3R$. It is presumed that all microballoons has uniform density ρ_{mb}. The glass and the tungsten are considered as porous matter. Therefor their compression characteristics are calculated as [3]:

$$K=\rho\cdot C^2;\quad E=3K\cdot(1-2\nu);$$
$$C=C_0\cdot(\rho/\rho_0)^{(\psi-1)/2};$$

where K, E, ν are bulk modulus, modulus and Poisson's factor for tungsten or glass; ρ, ρ_0 are densities of porous and normal tungsten or glass; C, C_0 are volume sound velocities for materials with densities ρ, ρ_0; ψ are constants for tungsten and glass.

Crushed microballoons (see fig.1) may appear at material fabrication. Effective characteristics (the density, bulk modulus and Gruneisen's factor) for the microballoon's crack, as well as for the crack-rubber mix, are calculated using mass part and volume part of tungsten and glass in the filling and the part of crushed GMB.

The metal covered GMB was considered as two-layer sphere. The effective bulk modulus of this sphere is

$$K_{mb}=\frac{2}{3}\cdot\left(\frac{E_w\left(h_w/R_w\right)}{1-\nu_w}+\frac{E_{gl}\left(h_{gl}/R_{gl}\right)}{1-\nu_{gl}}\right),$$

where h_w and h_{gl} are thicknesses for layers of tungsten and glass.

The effective Gruneisen's factor for metal covered GMB was determined by using of percolation model

$$\gamma_{mb} = \gamma_{cr}\left(\rho_{mb}/\rho_{cr}\right)^{\psi}.$$

The effective Gruneisen's factor for GMB-rubber material is

$$\gamma_{eff} = \frac{\varepsilon_{mix}\gamma_{mix}\rho_{mix}\rho_{mb}K_{mb} + \varepsilon_{mb}\gamma_{mb}\rho_{mb}\rho_{mix}K_{mix}}{\rho\left(x_{mix}\rho_{mb}K_{mb} + x_{mb}\rho_{mix}K_{mix}\right)},$$

where ρ is a GMB-rubber density; γ_{mb}, γ_{mix}, ε_{mb}, ε_{mix}, ρ_{mb}, ρ_{mix}, K_{mb}, K_{mix} are effective Gruneisen's factors, absorbed energy parts, densities and effective bulk modulus of metal covered GMB and crack-rubber mix respectively. Absorbed energy parts in components depends on flux type, atomic number of components and heat transfer.

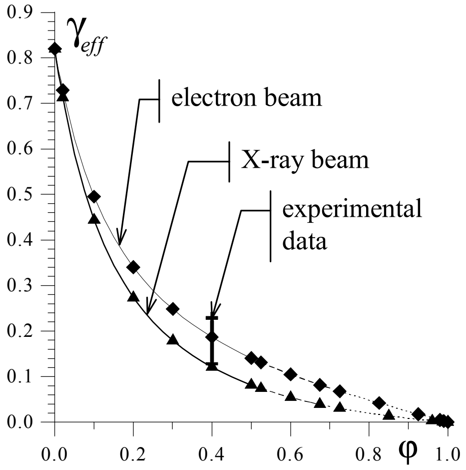

Fig.2. V.P. Efremov, V.E. Fortov et al

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Calculated dependences of the effective Gruneisen's factor as function of filling volume part for electron and X-ray pulse action are shown on fig.2 and compared with experimental data, obtained by measuring the particle velocity in the material with laser interferometer system. Investigated samples in these experiments are loaded by electron beam of 290 keV with pulse duration 100 μs. Calculated values are in good agreement with experimental one.

It was interest to exam the influence of GMB characteristics on initial pressure distribution the material. The GMB diameter, one's wall thickness, tungsten mass part and GMB crushed percent are varied. In all cases Gruneisen's factor decrease with filling volume part increasing. Also Gruneisen's factor decrease with GMB diameter increasing, as well as wall thickness, covering mass part and crack percent decreasing (see for example fig. 3, fig. 4). The differences in the GMB characteristics lead to differences in initial pressure generation in the GMB filled material (fig. 5) [2].

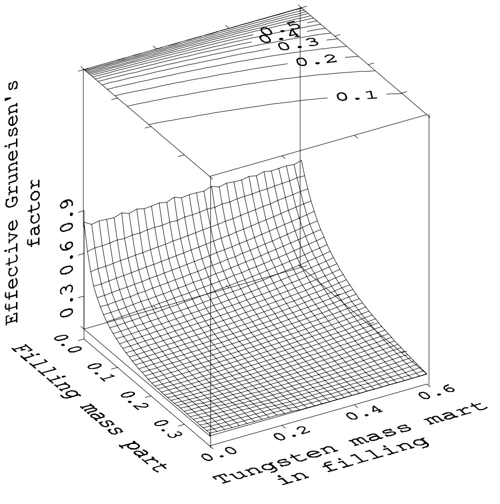

Fig.3. V.P. Efremov, V.E. Fortov et al.

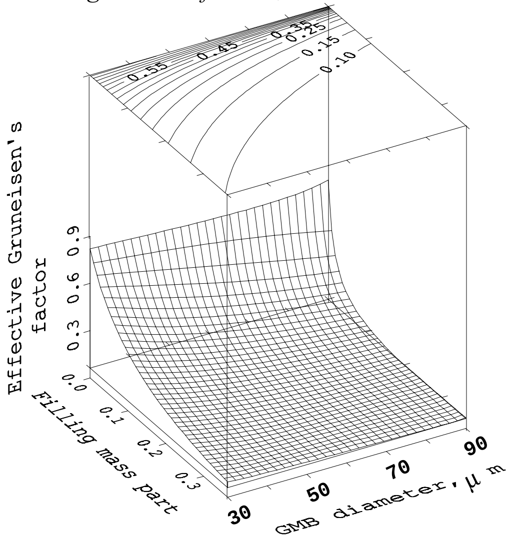

Fig.4. V.P. Efremov, V.E. Fortov et al.

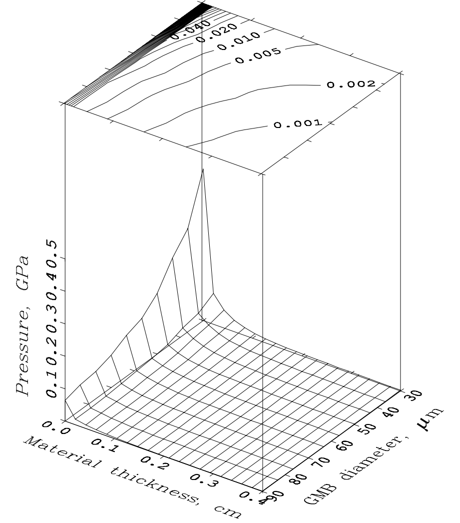

Fig.5. V.P. Efremov, V.E. Fortov et al.

2.2 Shock wave propagation

The area of initial pressure is a reason of shock wave. For the simulation of wave propagation the one-dimensional Lagrangian code was used. GMB-rubber heterogeneous material was considered as homogeneous porous elastic-plastic solid. The differential equation of state is used [4]:

$$dP = \overline{K}\frac{d\rho}{\rho^*} + \bar{\gamma}\rho^* \cdot dQ, \quad \overline{K} = \rho^*\overline{C}^2,$$

$$\overline{C} = C\left(\frac{\rho^*}{\rho}\right)^{\frac{\psi-1}{2}}, \quad \bar{\gamma} = \gamma_{eff}\left(\frac{\rho^*}{\rho}\right)^{\psi},$$

where C, γ_{eff}, ρ - the initial sound velocity, effective Gruneisen's factor and density of material; ρ^* – current density; Q - specific absorbed energy; $\overline{C}, \bar{\gamma}, \overline{K}$ – sound velocity, Gruneisen's factor and effective bulk modulus of the material with current density; ψ – percolation factor.

Two-layer sandwich structure (GMB-rubber bumper shield with organoplastik) was examined. Shock wave forming and moving are numerically studied. Tungsten mass part was varied. Microstructural analysis of the composite material after the pulse action was made. Areas of filler spall and the flux energy density leading to the GMB-rubber material spall was determined. Results of numerically study for various types of protection materials are shown in figure 6 (solid lines corresponds to 3.3 µs after irradiation, dashed – 5.3 µs; rhombus – 21.5% of tungsten, circles – 8.8% of tungsten). After passing the shock wave through the contact border of materials amplitudes of its positive and negative parts are increased.

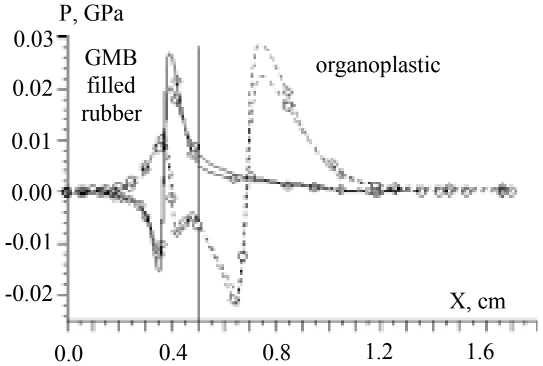

Fig.6. V.P. Efremov, V.E. Fortov et al.

This effect may be estimated by Hugoniot and isentrope curves in *P=f(U)* space analyse (in fig.7 curves are: 1 – organoplastic 2, 3 – GMB-rubber (8.8% of tungsten), 4, 5 – GMB-rubber (21.5% of tungsten)

In the considered interval of pressure the evolution of negative wave part is interesting as far as can lead to organoplastik spall. An increasing a negative amplitude of wave in the material in comparison with GMB filled rubber will be ≈50÷80% for considered pulse beam.

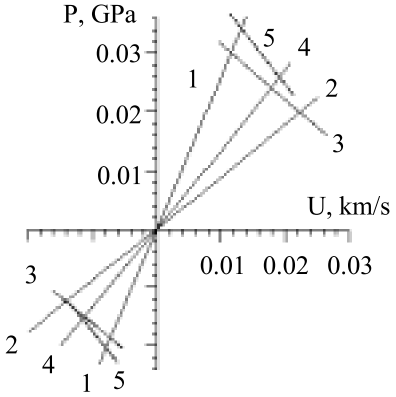

Fig.7. V.P. Efremov, V.E. Fortov et al.

3. Conclusion

In conclusion, presented model allows to describe interaction of powerful pulse beams with heterogeneous insulator material and can be use for optimisation of protection properties of composite material.

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