Interaction of Blast Waves with Multilayer Surfaces and Multiphase Media

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Abstract. The possibilities and methods of attenuation of blast waves when they are reflected on any limiting surface in terms of the peak pressure and momentum of the compression phase are of real practical interest. This interest stems from the need to eliminate or maximally mitigate the harmful effects of accidental and terrorist explosions. Porous materials are widely used in a variety of engineering structures due to their superior energy absorption capacity and other advantages in mechanical and physical properties. But when the porous material was used in protective structures to resist an explosive shock wave or high velocity impact, the protective function of the porous material was questionable. There are data indicating both a weakening and an increase in the explosive load on the protected object, depending on the structure of the porous material, the thickness of the protective layer, the duration of the positive phase of the blast wave pressure.

1. Introduction
Since the 60s of the XX century, active research and design developments have been carried out in the world aimed at controlling the high-explosive effect of an explosion using relaxation gas-saturated media of abnormally high compressibility.

Publications [1-15] in the world scientific literature indicate that one of the most effective ways to attenuate, for example, an underwater explosion is to surround the protected object with a layer of relaxation bubbly liquid. In relation to an air explosion, it seems more effective to place explosion-absorbing screens in the path of the blast wave, in the immediate vicinity of a dangerous charge of condensed explosives.

Another way to protect a protected technical or biological object from the high-explosive action of an explosive shock wave is the use of porous screens or multilayer linings, which also include multiphase media.

2. Materials and methods
The possibilities and methods of attenuation of blast waves when they are reflected on any limiting surface in terms of the peak pressure and momentum of the compression phase are of real practical interest. This interest is generated by the need to eliminate or maximally attainable mitigation of the harmful consequences of accidental and terrorist explosions. The same problems accompany the design of protective devices and special equipment used in the neutralization and destruction of a variety of explosive objects. To mitigate the undesirable effects generated by blast waves, multilayer coatings are
often used, including those with the inclusion of hard interlayers. The dangerous effects of an explosion include high-explosive, fragmentation, thermal and asphyxiation of targets. One of the difficult tasks in choosing protection measures is generated by the need to weaken high-explosive loads after an explosion. Quite often, cellular or foam materials are mentioned as promising explosion-absorbing materials. For the meaningful use of such materials in order to weaken the explosive loads, it is necessary to take into account all possible variants of the transformation of air blast waves by porous materials. Here, the success of using foam fillers for airbags in vehicles looks quite deceiving. Successful suppression of acoustic vibrations with open-cell and closed-cell foam samples also seemed promising. The complete picture of the influence of the physical properties and dynamic characteristics of porous materials on the transfer of explosive loads from the air through the screens to the target is still far from its exhaustive description.

Porous materials have been widely used in a variety of engineering structures due to their superior energy absorption capacity and other advantages in mechanical and physical properties. They are widely regarded as good shielding materials for suppressing shock waves, attenuating impulse loads and absorbing impact energy to protect structures, equipment and people.

However, when the porous material was used in protective structures to resist a blast shock wave or high velocity impact, the protective function of the porous material was questionable. There are data indicating both a weakening and an increase in the explosive load on the protected object, depending on the structure of the porous material, the thickness of the protective layer, the duration of the positive phase of the blast wave pressure.

Practically in all theoretical and experimental studies, models of samples with a simplified structure are considered as an object of action of shock waves. At the same time, in reality, the samples themselves can be covered with decorative or finishing materials, which can fundamentally change the nature of the interaction processes.

A study of the interaction of plane shock waves with compressible porous materials [16-19] showed that the maximum pressure amplitude on the wall under a layer of polyurethane foam can significantly exceed the pressure of normal shock wave reflection from a rigid wall in the absence of a porous coating.

3. Materials and discussion
The porous screen can enhance the action of the air blast with a stepped pressure profile on the target. The degree of wave amplification by the bulk medium may turn out to be higher than in the case of the consolidated medium. The degree of wave amplification essentially depends on the layer thickness, its structure, and grain size.

Practical applications related to the damping of pressure waves in a two-phase medium fall into two rather broad classes of problems, associated, respectively, with the amplification of pressure waves when passing into a harder medium and their weakening when passing into a medium with a reduced acoustic resistance. In this case, the fall of shock waves at the interface of two-phase media can lead to both its amplification in amplitude by a factor of 5-7, and to a weakening of its leading edge by a factor of 3-5, due to which almost complete attenuation of short-wave disturbances becomes possible (figure 1).

![Figure 1. The results of blasting a TNT charge weighing 0.5 kg, placed on a steel sheet raised above the ground. a) the charge is located directly on the sheet. b) the charge is placed in a blast-protection device "Fountain" [20-31].](image-url)
The protective properties of water-bubble screens in a liquid are determined by the ratios of the acoustic resistances of the liquid and the two-phase medium at both boundaries of the screen, with the pressure drop increasing on one of them and decreasing on the other. The convergence of the acoustic impedances of the liquid and the two-phase medium makes the protective screens "transparent" to shock waves and, therefore, ineffective. In this case, the efficiency of the screens strongly depends on the pressure in the medium, the volumetric concentration of gas bubbles and the intensity of the incident wave.

Efficiency of bubble screens with gas content less than 10% in relation to strong (\( \Delta p \geq 5 \) MPa) shock waves coming from an aqueous medium is rather low. Such bubble screens are not always effective in relation to weak (\( \Delta p = 0.1-0.2 \) MPa) shock waves.

Experimentally confirmed numerical results show that a decrease in the parameters of shock waves coming from a liquid by a gas-liquid layer can be expected only in the range of intensities from \( p_1/p_0 = 3-5 \) to \( p_1/p_0 = 30-40 \) at \( p_0 = 0.1 \) MPa and the volumetric gas content of the screen \( \beta_0 = 5-10\% \). Increasing the pressure in the environment to \( p_0 \geq 0.5 \) MPa narrows the range of "opacity" (ie efficiency) of the screen to the range of wave intensities from \( p_1/p_0 = 3-5 \) to \( p_1/p_0 = 15-20 \). Thus, conclusions should be drawn about weak damping of shock waves with both too large and too small pressure drops. So, at \( p_0 = 0.1 \) MPa and \( p_1/p_0 = 2.4 \) the pressure drop at the front of the shock wave, the gas-liquid screen decreases by only 2 times, and at \( p_1/p_0 = 13 \) only by 20-30%.

4. Conclusion
Despite a noticeable decrease in the amplitude of the leading front of the shock wave, the protection of industrial structures, humans or animals with multilayer coatings, as a rule, is ineffective in the sense that it does not lead to a noticeable decrease in the maximum overpressure on the protected barrier. Indeed, the presence of a reasonably designed coating leads to a weakening of the leading front of the wave acting on the obstacle, but at the same time - to the formation of reflected waves, which are again reflected from the interfaces and arrive at the protected surface, as a rule, in the form of new (secondary) waves compression. If the thickness of the multilayer coating is noticeably less than the length \( L \) of the positive pressure phase in the incoming air wave, then the secondary compression waves after several reflections and refractions reach the protected surface and bring the excess pressure on it to a value approximately equal to the excess pressure in the absence of coating. A noticeable decrease in the maximum shock-wave load on the protected barrier is achieved only if the thickness of the protective coating is comparable to the characteristic size of the positive phase. In this case, the secondary waves fall under the influence of the unloading wave (pressure drop behind the leading edge) and are attenuated even before they reach the surface of the protected object. Unfortunately, the required thickness of a multilayer protective coating can only be achieved in personal protective equipment in the rarest of cases. Otherwise, it is rather not a decrease in the amplitude of the blast wave that is observed, but a "flattening" of its front.

5. References
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