PATTERNS AND MECHANISMS OF INTERACTION OF RADIOACTIVE CARGO RADIATION WITH METAL-Glass LAYER OF WATERCRAFTS STRUCTURE

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Abstract. The article discusses the use of new metal-glass materials and coatings with steel and aluminum matrix, filled with hollow glass microspheres, as the structures protective layer of floating constructions which serve as transshipment and temporary storage points of radioactive substances of low and medium activity. The purpose of work is to establish patterns, to investigate processes and mechanisms of interaction of ionizing radiation with a protective metal-glass layer. The protective layer can be formed in plates by hot pressing method and with the help of radiation-resistant adhesives can be attached to the surface of structures; it is also possible to form it by electric-arc spraying. The work represents a set of theoretical researches based on modeling of interaction of ionizing radiation with the structural elements of metal-glass compositions, and contains new scientific information about patterns and mechanisms of formation of the protective properties. As an experimental evaluation criteria was adopted the mass attenuation coefficient of X-ray radiation, which characterizes the maximum protective ability of materials at their minimum density. The comparison of X-ray protective properties with other kinds of syntactics and coatings filled with solid particles of sodium-silicate and lead-containing glass showed that the properties of the metal-glass compositions are not inferior to counterparts. The research results can be used in structures designing of floating constructions for transportation of radioactive materials.

Keywords: hollow glass microspheres, composite materials, syntactic foam, radioactive cargo, matrix, structural element, surface of phase section, model of cell, coatings, attenuation coefficient of radiation, structures, floating constructions.

Introduction

Contemporary experience of maritime transportation of radioactive substances of low and medium activity involves the exploitation of specialized floating constructions as transshipment and temporary storage points (Luna, 2004). Cargo, which is transported in special containers, is placed inside the structures of biological protection (Sannen, 2007). Most of the accumulated wastes are substances of low and medium activity (wasted sources of γ-radiation, X-ray tubes, pieces of laboratory equipment, overalls), which continue to be a source of ionizing radiation (the radiation) and have a direct impact on the materials of structures (Vieru and Mihaiu, 2012). The current practice involves coating of the irradiated surface with the additional absorbing layers, which are composed of radiation-resistant materials and coatings and which properties are structurally dependent. In current practice for protection from radiation are preferred heterogeneous also porous materials and poly- and ultradispersed compositions (Trofimov, Pleshkov and Back, 2006). Such compositions are structurally inhomogeneous materials of syntactic type, filled with hollow glass microspheres: rubber, spheroplastics, which have X-ray protection properties and low thermal conductivity (Li and John, 2008). To increase the reflectivity in the process of manufacturing glass microspheres are subjected to metallization; it creates additional section surface in a structurally inhomogeneous layer, improves their thermal conductivity and reflectivity (An, Zhang, 2012). The disadvantages of such materials are the destruction of microspheres during the metallization and high cost of technologies (Zhang, Wu and Zhao, 2005). The alternative is metal-glass composite materials and coatings with aluminum and steel matrix, filled with hollow glass microspheres (Kazymyrenko, 2013).
The purpose of work is to establish patterns, to investigate processes and mechanisms of interaction of ionizing radiation with a protective metal-glass layer filled with hollow glass microspheres (the microspheres).

Results

The diffusion flux of ionizing radiation (the radiation), the source of which is radioactive substance, interacts with the metal-glass composite layer, which consists of steel or aluminum matrix filled with microspheres. Depending on the type of radiation composite layer can fully absorb the radiation energy or reduce it to a certain number of times (Chittineni and Woldesenbet, 2010). Aluminium-matrix composite layer can be manufactured by method of hot pressing of moldable powder mixture or powdered aluminum with microspheres; technology allows to vary the volume content of microspheres in a wide range (Kazymyrenko, 2013). Products are made in the form of tiles and with the help of radiation-resistant adhesives or compounds can be attached to the surface of structures. Protective layer can also be applied by the electric-arc spraying; steel or aluminum welding wire is used for formation of metal matrix, as filler - hollow glass microspheres, volume content of which is limited by technology and is 40 ± 7% (Kazymyrenko, 2013). The protective layer of structures of biological protection must provide maximum absorption of ionizing radiation in conjunction with minimum density, which is formed by creating of necessary structural characteristics.

The research was based on the model of unit cells, which were worked out based on microstructural investigations, the results of which are presented in works of Kazymyrenko Y. (2013). In the problem statement were introduced assumptions about the neglect of angle of coherent scattering of the radiation flux at the outlet of the cell; about the identity of mechanisms of interaction of all types of ionizing radiation, including γ- and X-rays with the structural elements and cells of compositions and also about the permanence of cell volume under irradiation. The interaction of flows with unit cells was discussed in view of basic laws of radiation materials science (Was, 2007). These theoretical researches were confirmed experimentally on laboratory X-ray sources; mass attenuation coefficient of ionizing radiation \( \mu_{\text{mass}} \) was selected as the criterion, which was presented in relative units and characterizes the ability of materials with the lowest density maximally attenuate the radiation flux (Kazymyrenko, 2013). Results were compared with other kinds of syntactics: with spheroplastics and syntactic foam glass and also with electric-arc coatings filled with solid particles of sodium-silicated and leaded glass.

Researches of mechanisms of interaction of ionizing radiation with a protective composite layer include the analysis of the processes, which are occurring in metal-glass materials and coatings based on their structural characteristics. By its structure, all contemplated compositions are porous polydispersed structurally inhomogeneous media in which the glass particle is a major structural element. Also, the porous medium of metal matrix and the surface of metal – glass section directly influence on the mechanisms of attenuation of ionizing radiation.

The model of cells of metal-glass compositions is shown on Fig. 1, research is based on the mechanisms of radiation attenuation by structural elements: glass particles (Fig. 2a, b) and the pores (Fig. 2c).

![Fig.1](image.png) The model of elementary cells of compositions filled with hollow glass microspheres: \( I_0 \) - incident flux; \( R' \) - reflected flux; \( R \) – flux absorbed by the particle; \( I' \) - scattered flux; \( I \) - transmitted flux

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Fig. 2. Interaction of ionizing radiation with structural elements:
a - hollow glass microsphere; b - solid glass particle; c – pore

In work are discussed hollow glass microspheres of sodium-silicated composition with an average dispersion of 40 ... 60 mm and a wall thickness of 1 mm, which, according to the manufacturing technology, are filled with sulfuric anhydride $\text{SO}_3$. For comparison, in article is considered the interaction of ionizing radiation with solid particles of sodium-silicated and leaded glass, which dispersion is also 40 ... 60 mm. During the manufacturing of compositions with hot pressing and electric-arc spraying methods used microspheres and glass particles retain their shape and amorphous state. A feature of structure of steel electric-arc coating is the formation of iron silicide $\text{Fe}_5\text{Si}_3$ with coherent lengths 85 ... 110 nm at the surface of steel - hollow glass microspheres sectionphase. The surface of aluminum - hollow glass microspheres compositions phase section is the microsphere wall thickness of 1 micron. In hot pressed glass-aluminum materials, depending on the technological modes, can appear the glass-phase interlayer between sintered hollow glass microspheres. The porosity of obtained materials and coatings, depending on the technological modes, is in the range of 10 ... 22%.

Fig. 3. The mass attenuation coefficient of ionizing radiation by composite materials and coatings:
1 - covering of aluminum-microspheres composition; 2 - hot-pressed Al powder-microspheres composition;
3 - hot-pressed Al dust-microspheres composition; 4 - syntactic foamed glass; 5 - aluminum coating without filler; 6 - spheroplastic; 7 - coating of steel - microspheres composition; 8 - spheroplastic with extra porosity;
9 - coating of steel - leaded glass composition; 10 - coating of steel – sodium-silicated glass composition;
11 - steel coating without filler

The basis of the formation of protective properties of metal-glass materials and coatings is the effect of attenuation of ionizing radiation flux by hollow glass microspheres: by the time the flux passes through microsphere (Fig. 2a) there is a triple energy flow absorption by walls and gas environment inside microspheres; the absorption is enhanced by increasing the volume content of microspheres in compositions, wherein $R_0$ flux is reflected from the glass microsphere in a heterogeneous environment. In compositions filled with solid glass particles (Fig. 2b), part of passing flux $R_0$ is reflected and the next portion of the flux is absorbed by solid glass environment, wherein in its entire volume there is a continuous elastic scattering of radiation energy. The porous structure of the matrix increases the anisotropy of the matrix and changes the flux trajectory $I_0$, consequently, on the surface of the pore occurs the multiple scattering of energy: incident radiation flux $I_0$, passing through the unit cell, scatters around the pore with energy of dissipation $I'$, is partially reflected from the hollow glass microsphere $R_0$, it is partially absorbed by it $R$ and then passes to the
next elementary volume; on the surface of metal-glass section there is an additional energy dissipation. Thus, in a heterogeneous environment of developed metal-glass compositions is observed the effect of multiple internal reflection from the glass particles into a structurally inhomogeneous porous environment of metallic matrix absorption. For compositions with an aluminum matrix, this effect is enhanced by properties of the porous aluminum matrix, in which there is multiple reflection of radiation fluxes and their additional scattering around the pores, as evidenced by high value of \(\mu_{\text{mass}}\) for aluminum-matrix materials and coatings compared to the composition of steel-microspheres (Fig. 3).

A qualitative comparison of the obtained data with other materials has shown that X-ray protective properties of the steel-microspheres composition are on the same level with known analogues: varieties of spheroplastics and syntactic foamed glass, which are inferior to aluminum matrix materials (Fig. 3). \(\mu_{\text{mass}}\) values for compositions filled with microspheres by 25 ... 30% higher than the same index for coatings filled with solid particles of sodium-silicated and leaded glass. The introduction in steel and aluminum electric-arc coatings composition up to 50% (by volume) of hollow glass microspheres increases the value of \(\mu_{\text{mass}}\) in 2 ... 2.5 times and reduces its density by 15 ... 25%. The use of lightweight composite materials and coatings is an important factor for shipbuilding technologies aimed at reducing the weight and size of structures.

Discussion

As a result of the research we have obtained new ideas about the mechanism and the nature of the interaction of ionizing radiation with metal-glass composite layer filled with hollow glass microspheres and solid glass particles. In proposed model have been taken into account basic physical processes of interaction of the diffusion flux of ionizing radiation with the structural elements and elementary cells isolated from the array of metal-glass composite layer. The research results can be used for designing structures of biological protection of floating constructions. Further works are associated with the modeling of thermomechanical processes that occur in the protective layer of structures under the influence of thermal effects.

References


