CONTROL OF MACROSCOPIC CHARACTERISTICS OF COMPOSITE MATERIALS FOR RADIATION PROTECTION

V.F. Klepikov, E.M. Prokhorenko, V.V. Lytvynenko,
A.A. Zakharchenko, M.A. Hazhmuradov**
Institute of Electrophysics and Radiation Technologies NAS of Ukraine, Kharkov, Ukraine;
**NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine*

Composite materials, intended for radiation protection, were studied. They are made of polystyrene and reinforced by an aluminum. Aluminum is used as a powder. Tungsten powder was added for increase the radiation-protective properties. Examined the state of the composite material at different temperatures. The composite material is dependent on the component. Thermal conductivity of the composite material was studied. It was used in the form of balls and plates. The absorbed dose of gamma-radiation is calculated by mathematical methods. The area where the maximum absorbed gamma quanta found for composites.

PACS: 681.2, 615.471

INTRODUCTION

Radiation protection of equipment and personnel is an essential requirement of safe operation of nuclear facilities. For this purpose, different materials are used. Improving the efficiency of protection against ionizing radiation requires improvement of existing and development of the next generation of protective materials. Creation of new materials based on a combination of components with different physical characteristics. The use of composites allows to obtain a material with the desired characteristics in accordance with the requirements [1, 2].

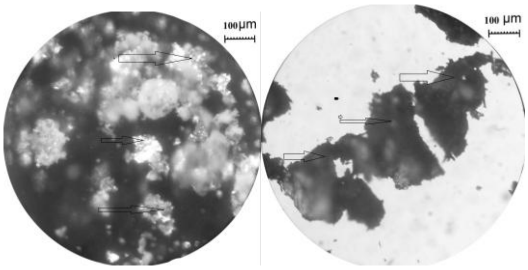
PURPOSE OF WORK

The aim of this work is the study of the macroscopic structure of the composite material to improve the performance properties. Also investigated the thermal conductivity and hardness of the composite depending on the composition and structure of the components.

THE MAIN PART

On the creation of materials for biological protection received considerable attention. Nowadays a huge number of known materials used for protection against ionizing radiation. Among them, a series of composites where polystyrene is used as the basis of [2, 3]. He is a good insulator, has a low chemical activity, has minimal sorption of radioactive substances. The choice of polystyrene as basis is also grounded, by his not high cost and simplicity of treatment. He effectively takes in gamut quanta with energies to 110 keV [4]. However, it should be noted that at the protracted influence of radiation polystyrene can collapse [5]. For diminishing of this destructive process reinforced polystyrene different additions. In our case applied the aluminum alloy of AMg2, which was used, as powder.

Radiation-protective properties of pure polystyrene small for high-energy gamma rays. Additives used high barrier characteristics. Absorbs gamma and X-ray powder tungsten. Are shown in Fig. 1 the metal components of the composite material.



a b

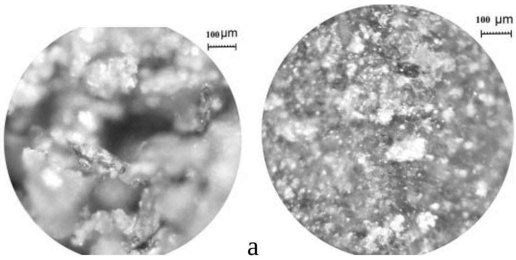
Fig. 1. Starting powder component:
a – aluminum alloy AMg2; b – tungsten

On Fig. 1,a the picture of powder of aluminum alloy of AMg2 is presented. Used powder, made in accordance with specifications TU 1791-99-024-99. He has a size of separate element equal 10…20 μm. Lumps are visible which separate grains of aluminum (pointers to separate grains) are in. On Fig. 1,b initial component of tungsten with the size of element of 200…250 μm. Pointers are directed in separate grains. Applied model powder, which corresponded to the values specifications TU 48-19-101-84.

For basis of composite used polystyrene of brand of PSM-115 (GOST 20282), as granules. The choice of this type of polystyrene is conditioned by a few parameters. Polystyrene of PSM-115 has a low price, wide distribution of application, application developed processing technology, presence of industrial equipment (molds, etc.). Making of composite material was produced on an industrial equipment which was exposed to the insignificant revision. On a capacity which heating and interfusion of components is in, was placed 814 Ti-imager. His sensitiveness is 0.08 °C, with, that allows to educe all deviations from the recommended temperature. With his help control of uniformity of heating of material and homogeneity of distribution of components was carried out on volume mixtures [2]. Working off the methods of preparation of mixture was conducted on vertical injection molding automat of VLM-150. The production of composite material was carried out on injection molding automat of KUASY 1400/250.

However, samples with maximum uniformity of the metal components by volume of the composite material, it was possible to obtain with injection molding machine using WINDSOR SP 30. This apparatus is intended for the manufacture of articles of reinforced plastics. Obtain several samples of composite materials with different contents of tungsten and aluminum. We studied the structure of the samples.

Photographs of their internal structure, made at a temperature of 20 °C are shown in Fig. 2.



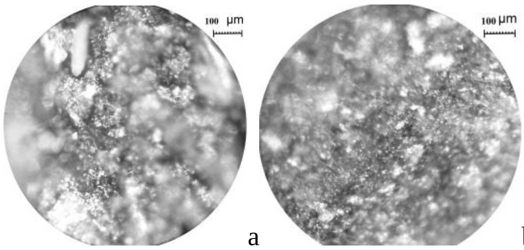
a b

Fig. 2. The structure of the composite material at a temperature of 20 °C: a – C080601; b – C080106

These composites have the same volume and the metal constituting the polystyrene component. The difference in the composition of the bulk tungsten and aluminum. This is clearly seen in the photographs of structures of composite materials. Metal component material C080601, shown in Fig. 2,a includes tungsten component having six volumes and component of aluminum having one volume. Fig. 2,a on the structure of the material witness large grains of tungsten, which are surrounded by polystyrene and shallow aluminum particles. It is seen that the cutoff region, the arrangement is homogeneous. Based on this, we can conclude that the tungsten component is distributed on the volume of the composite material uniformly. Material made in accordance with the requirements. Filling polystyrene and aluminum evenly.

On Fig. 2,b shows a photograph structure of C080106. As part of its metal components tungsten volume one and six volumes of aluminum. The bulk of the surface occupied by aluminum particles interspersed with tungsten. Their distribution is also uniform. Similarly, it was considered distribution of the metallic component of the composite material by volume. The photographs were not detected cavities between component elements. Look continuous basis (polystyrene) of the whole space of the material.

In order to determine changes in the structure of materials were tested calorimetric studies. Studied issues such interaction of the components of the composite material and the chemical reactions between them. For this heating of the samples was performed. Maximum heating to the softening temperature of polystyrene. The softening temperature of polystyrene PSM-115 above 95 °C. Temperature control is also carried out by the thermal imager. This allows us to analyze the change in the temperature field over the entire surface of the sample. During heating of the samples was carried out to study sections. Photographs were taken of the samples at 40 and 60 °C. At higher temperatures the survey was performed, although the observation was carried out. The first picture is taken when the temperature was 20 °C. Pictures of composite materials when their temperature was 60 °C, are shown in Fig. 3.



a b

Fig. 3. The structure of the composite material at a temperature of 60 °C: a – C080601; b – C080106

Fig. 3,a on a photograph of the cut surface of the composite material C080601, which is heated to a temperature of 60° C. As in the case shown in Fig. 2,a, observe individual grains of tungsten. The space between them, is filled with particles of aluminum polystyrene. Fig. 3,b on the cut surface is a photograph C080106 composite material that has been heated to a temperature of 60 °C with a photo image similar Fig. 2,b, which shows the cut surface of the same material at a temperature of 20 °C.

The space is filled with polystyrene with aluminum particles, individual points are located tungsten particles. All photos shows a uniform distribution of metal components in space polystyrene. There are no cavities, homogeneous filling. Homogeneity and uniformity of the component in terms of the composite material is needed to improve the radiation-protective characteristics. Fig. 2 of the photos we see that at the boundary of grains tungsten and aluminum are no voids, cavities. There was a full sticking with polystyrene. A similar pattern is observed in Fig. 3. Consequently, the entire range of temperatures, the melting temperature, the structure of the composite material is constant and no conversion interaction.

The material is in stable condition. Sealing composite material is not only due to the metal component of additives, but also due to stretching of the polymer chains. Note that when heated to the softening temperature, no chemical reaction. This applies both to chemical reactions between the individual component elements and chemical reactions between tungsten and aluminum, tungsten, and polystyrene, aluminum and polystyrene.

Obtained from raw materials produced 1, 2, 4 mm diameter balls. Application of the protective material in the form of balls, fill maximizes the protective layer and making flexible protection. The requirement for flexibility is important in the manufacture of radiation protection of personal protective equipment. One of the conditions that apply to the developed composite materials, was the presence of high heat-shielding characteristics. Checking the thermal conductivity of composite materials was carried out as follows. Infrared source placed behind the sample. The heating temperature can be adjusted. The distance from the source to the rear surface of the sample is set to 1 mm.

Source temperature was chosen to be 60 °C. With Ti-814 controlled temperature change on the front wall of the sample. It was possible influence of air currents, reflected light and other factors that distort the results. Studied the temperature rise as a function of time. Experiments were conducted for various materials. The results of testing the thermal conductivity of composite materials are shown in Fig. 4.

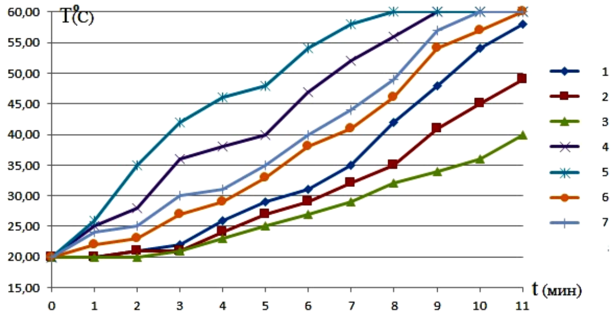


Fig. 4. Graphs of growth surface temperature composite materials

Curve 1 in Fig. 4 corresponds to an increase of temperature with time on the surface of a sample 10 mm thick polystyrene. Solid polystyrene. Curve 2 is the temperature dependence of the layer thickness of 10 mm polystyrene, but produced in the form of balls with a diameter of 2 mm. Curve 3 – for a layered polystyrene which has two cavities in a thickness of 1 mm. It was obtained numerically. This curve has a minimum conductivity characteristics so as to rupture the cavities of the heat flux. At these points, the diffusion heat transfer radiative heat transfer is replaced, which is much smaller. Maximum heat-conducting properties in solid polystyrene sample. Layer, which is filled balloons, thermal conductivity is between these curves. This is due to the fact that when the volume filling balls are formed gaps which slows down the thermal flow. The greater the spacing, the less heat flux. However, at the points of contact between the side surfaces of the balls, the heat transfer is diffusion continuously. Curve 4 corresponds to the change in temperature on the surface of the sample composite material C080601. Curve 5 for C080106.

In the study of these materials are used in the form of solid plates with a thickness of 10 mm. Temperature change occurs of similar laws. Observe a smooth increase with time. Note that the thermal conductivity increases with the metallic component in the material. The volume content of the metal components in our composite material was 45%. The heat flow through the sample C080106 higher than the heat flow through the sample C080602. The reason for this is the higher thermal conductivity of aluminum (237 W/mK) than the thermal conductivity of tungsten (173 W/mK). In the study of these composite materials, but made in the form of balls with a diameter of 2 mm and a thickness of the protective layer 10 mm following results were obtained. The temperature increase on the surface of the samples occurs more slowly than in the case of a solid material. As in the case of continuous heating of the composite materials C080601 (curve 6) is slower than C080106 sample (curve 7), due to the larger amount of tungsten in the composition of the metal component. It can be seen that the graphs 6 and 7 at the initial stage have a smooth rise than the temperature graphs 4 and 5. This is due to slowing the spread of the heat flux at the hollow at the initial time.

The main challenges posed by the development of composite materials, increasing radiation-protective properties. Determine the effectiveness of radiation shielding materials received, carried out by numerical methods using simulation package interactions of nuclear radiation with matter Geant4 [6]. The results obtained by numerical methods are in good agreement with the experimental data [7]. Depending weakening of the absorbed dose for composite materials that have been studied above, are shown in Fig. 5.

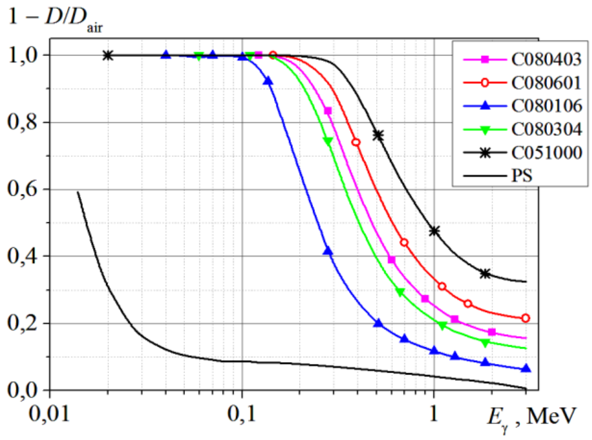


Fig. 5. Weakening of the absorbed dose of gamma radiation protective layer of the composite material

Mass component values are shown in Table.

Mass components of composite materials

Material	Polysty-Rene (PS), mas.%	Tungsten (W), mas.%	Aluminum (Al), mas.%
C080601	6.9	91.0	2.1
C080403	9.4	82.0	8.6
C080304	11.4	74.7	13.9
C080106	19.9	43.6	36.5

All samples were completely absorb gamma rays with energies up to 200 keV. The layer thickness was 10 mm. In the calculations take into account that the material component. The material consists of spheres with a diameter of 2 mm. With increasing energy gamma rays protective characteristics of the submitted samples are reduced. Half of the sample C080106 weakening occurs at an energy of 300 keV. Maximum radiation-protective properties has composite C080601. For him, the energy half-attenuation value is 70 keV. For all samples absorbed 10…30% of gamma rays with an energy of 1 MeV.

Thus obtained composite materials provide high protection against radiation of gamma rays in the energy range up to 200 keV. Namely, in this range, emits the maximum amount of industrial sources. Note that most of the X-ray machines, which are used in dentistry, working with gamma rays of 68 keV.

CONCLUSIONS

1. Designed and manufactured polystyrene-aluminum composite radiation-protective materials.

2. It is shown that at the change of temperature of samples to the temperature of softening influence of polystyrene (95 °C), there is not violation of structure of material.

3. The thermal conductivity of composite materials has been verified experimentally.

4. A comparison of the characteristics of the heat protective samples made in the form of plates and in the form of balls

5. Numerical methods, the dependence of the absorbed dose attenuation of gamma radiation on the composition of the composite.

REFERENCES

1. E.M. Prohorenko, V.F. Klepikov, V.V. Lytvynenko, A.I. Skrypnik, A.A. Zaharchenko, M.A. Hazhmuradov. Improving of characteristics of composite materials for radiation biological protection // *Problems of Atomic Science and Technology*. 2013, N 6(88), p. 240-243.

2. E.M. Prohorenko, V.F. Klepikov, V.V. Lytvynenko, A.A. Zaharchenko, M.A. Hazhmuradov. Metal containing composition materials for radiation protection // *Problems of Atomic Science and Technology*. 2014, N 4(92), p. 125-129.

3. V.N. Gulbin. Development of the composite materials modified by nano powders, for radiation protection in atomic engineeringю // *Nuclear Physics and Engineering*. 2011, v. 2, N 3, p. 272-286.

4. E.M. Prohorenko, V.F. Klepikov, V.V. Lytvynenko, A.I. Skrypnik, A.A. Zaharchenko, M.A. Hazhmuradov. Improvement of characteristics of composite materials for biological protection from nuclear radiation // *Abstracts of the XXIII International conference on accelerating of the charged particles*. Alushta, September, 08–14, 2013, p. 158.

5. V.I. Dubinko, V.F. Klepikov. The influence of non-equilibrium fluctuation on radiation damage and recovery of metals under irradiation // *Journal of Nuclear Materials*. 2007, v. 362, p. 146-151.

6. S. Agostinelli, J. Allison, K. Amako. Geant4 – a simulation toolkit // *Nucl. Instr. & Meth. A*. 2003, v. 506, p. 250-303

7. A.A. Zaharchenko, A.I. Skrypnik, M.A. Hazhmuradov, E.M. Prohorenko, V.F. Klepikov, V.V. Lytvynenko. Simulation of characteristics of gamma-radiation detectors based on mercury compounds // *Problems of Atomic Science and Technology*. 2013, N 3(85), p. 231-235.

Статья поступила в редакцию 06.02.2015 г.

КОНТРОЛЬ МАКРОСКОПИЧЕСКИХ ХАРАКТЕРИСТИК КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ РАДИАЦИОННОЙ ЗАЩИТЫ

В.Ф. Клепиков, Е.М. Прохоренко, В.В. Литвиненко, А.А. Захарченко, М.А. Хажмурадов

Изучались композиционные материалы, предназначенные для радиационной защиты. Они базировались на полистироле, который армировался порошковым алюминием. Увеличение радиационно-защитных свойств осуществляли добавлением порошкового вольфрама. Проводилась проверка состояния материалов различного компонентного состава в зависимости от температуры. Изучались характеристики теплопроводности композиционных материалов, выполненных в виде сплошных пластин и шариков. Математическими методами вычислена энергетическая зависимость поглощенной дозы гамма-излучения для полученных образцов. Определялись диапазоны энергий гамма-квантов, при которых применение композиционных материалов наиболее эффективно.

КОНТРОЛЬ МАКРОСКОПІЧНИХ ХАРАКТЕРИСТИК КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ РАДІАЦІЙНОГО ЗАХИСТУ

В.Ф. Клепіков, Є.М. Прохоренко, В.В. Литвиненко, О.О. Захарченко, М.А. Хажмурадов

Вивчалися композиційні матеріали, призначені для радіаційного захисту. Вони базувалися на полістиролі, який армувався порошковим алюмінієм. Збільшення радіаційно-захисних властивостей здійснювали додаванням порошкового вольфраму. Проводилася перевірка стану матеріалів різного компонентного складу залежно від температури. Вивчалися характеристики теплопровідності композиційних матеріалів, виконаних у вигляді суцільних пластин і кульок. Математичними методами отримана енергетична залежність поглиненої дози гамма-випромінювання для отриманих зразків. Визначалися діапазони енергій гамма-квантів, при яких застосування композиційних матеріалів найбільш ефективне.