GRINDING THE SPENT NUCLEAR FUEL SIMULATING MATERIALS FOR THE MAGNETOPLASMA SEPARATION

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Consideration is given to the three methods used for the grinding of materials simulating spent nuclear fuel, in particular underwater spark discharges, the static compression and the laser sputtering. These methods were compared by measuring the sizes of obtained materials. The preference is given to the methods of static compression and the pulse laser sputtering.

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INTRODUCTION

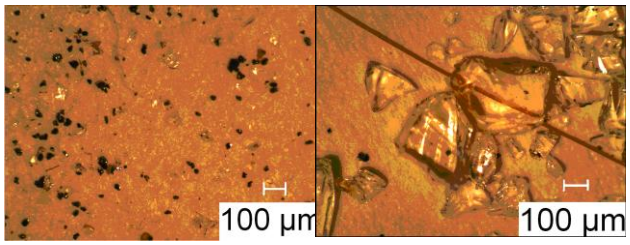
The electrohydraulic method used for the grinding of glassy materials that simulate the content of fuel elements was studied in [1]. Physical methods of the regeneration of nuclear fuel waste are given in [2, 3]. To speed up the removal of admixtures it is proposed to use the powdery fuel elements with particle sizes of approximately 50 to 100 μm instead of bulk fuel elements. Such powders with simultaneous removal of admixtures can be obtained in HF plasma reactors and by grinding the glassy content of fuel elements. This paper gives consideration to the electrohydraulic method, the method of mechanical static compression, and the method of pulse and continuous laser irradiation.

The purpose of this paper is to obtain experimental data on the grinding of materials that simulate solid radioactive waste, using three proposed methods, and find out if the particles of 100 μm can be obtained for the specimens treated. The UO_2 fission results in the formation of an ample quantity of pre-uranium elements. These elements are formed at high temperatures that reach metal melting temperatures and that allows for the formation of different complex alloys. The NiCoCr alloy was taken as a model. A content of the zirconium tube filled with uranium is vitrified; therefore we selected for the experiments the remelted prefabricated glass. The specimens of glass, ZrO and NiCoCr were also chosen because of their hardness that is similar to that of fuel releasing elements. Consideration is also given to the problems of the purity of obtained materials, environmental pollution and the nuclear safety.

EXPERIMENTAL PART

The "HYDRA" plant was used to carry out the experiments on the grinding of materials that simulate solid radioactive waste, using the electrohydraulic method and consideration was given to them in [1].

Fig. 1 gives the pictures of specimens subjected to the electrohydrauic pulse grinding in the water. After the separation using the screen the destroyed material was distributed by the fractions. The sizes of obtained specimens varied in the range of the units of microns to 5 mm.



a *b*

Fig. 1. Pictures of the specimens of glass grinded using the electrohydraulic pulse method, as seen through the optical microscope:
a – the specimens with the size less than 1 mm;
b – the specimens with the size more than 1 mm

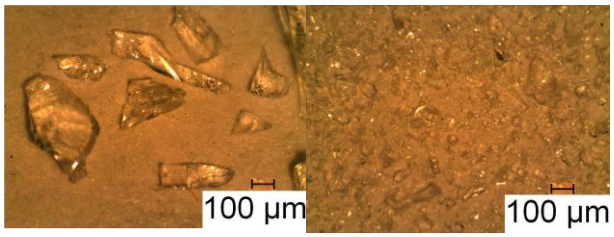
It has been established that the content of particles with the size less than 1mm is not exceeding 15% of the total mass of processed specimens. In addition, the finest particles were covered with the scale or were melted due to high temperatures near the discharge channel. To increase the efficiency of the given method it is necessary to increase the amount of energy input into the pulse and update the structure of working chamber to make the distribution of shock waves more efficient.

The mechanical method used for the grinding of simulation models was based on the static pressing. The elements of operating units of the high pressure cylinder (HPC) (the compression ram with the lead gasket) are given in Fig. 2.

Fig. 2. High pressure cylinder with the embedded simulation glass specimen

Fig. 3 gives the pictures of specimens subjected to the static compression. After the separation using the screen the destroyed material was distributed by the fractions. The sizes of obtained specimens varied in the range of the units of microns to 3 mm. It has been

established that the particles with the size less than 1 mm make up 50 to 100% of the total mass of processed specimens. Particles subjected to the processing retain the initial purity and actually contain no traces of the lead gaskets of compression ram.



a *b*

Fig. 3. Pictures of the specimens of glass grinded using the method of pressing, as seen through the optical microscope; a is a typical size of the specimens grinded by applying a force of 20 scale marks (3320 kgF/cm^2); b is typical size of the specimens grinded by applying a force of 80 scale marks (3320 kgF/cm^2)

The energy spent for destruction of the ball was defined using the following relationships:

$W = P\Delta V/2 = F\Delta H/2, \qquad P = F/S = F/\pi Ø^2/4,$

where ΔH is the high pressure cylinder relief after the specimen destruction, mm. S is the area of HPC, $Ø \sim 100$ mm. The sample was destroyed at the scale marks of dynamometer of 20, 30, 70, and 80, where 1 division corresponds to 166 kgF.

Hence, the minimum and maximum values of the energy required for the destruction of simulation specimens are 30 to 130 J accordingly, which complies with the energies of electrohydraulic pulse method, where up to 30% of the stored energy is converted into the energy of shock waves.

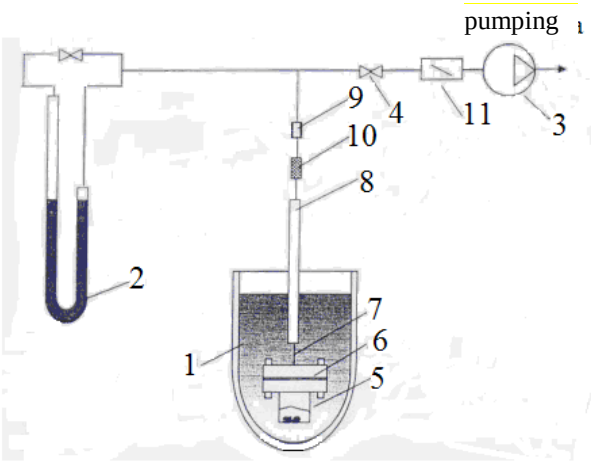


Fig. 4. The device used for the measurement of specific surface using the BET method, where 1 is the vessel filled with the liquid nitrogen (Cryostat); 2 is the mercurial differential manometer (pressure measurement system); 3 is the forevacuum pump; 4 is the gas inlet valve; 5 is the measurement chamber; 6 is the measurement chamber cover; 7 is the delivery capillary; 8 is the vacuum jacket; 9 is the breech-block; 10 is the filter; and 11 is the nitrogen trap

The specific surface of the particles or the size of fractionated phase was determined using the BET (Brunauer-Emmett-Teller) method. This method is based on the ability of gases to adsorb on the material surface. In our case the working gas is nitrogen. Tested samples are trained through the heating to 300 °C during 10 to 16 hours under the forevacuum pumping. The error of this method is ± 10%. The paper [8] describes the application of this method with more detailed description of the device given in Fig. 4.

A specific surface S of the specimens destroyed in different conditions has been determined, see the Table. The measurement error was ± 0.025 g/m^2. It can be seen that with an increase in the energy W spent for the destruction the specific surface S is also enlarged, and as a result the number of small particles is also increased.

W, J	S, g/m^2
30	0.362
50	0.394
115	0.481
130	0.561

The laser destruction or the material sputtering can be used as alternative methods. The experiments were carried out using two types of lasers, in particular of pulse and continuous action up to 5 kW and 80 W, respectively. The speech is about the pulse laser "Vizard 80" and CO_2 laser PL-1600 with the beam diameter of 2 mm operating in the continuous mode.

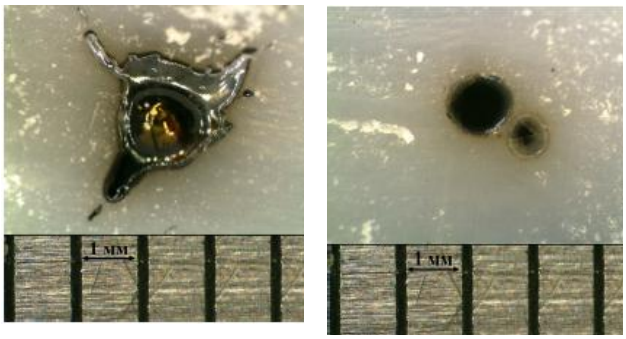
The experiments showed that these lasers differ also in their action on the specimens. In the case of the laser operating in the continuous mode the action has an inertial character and it is manifested on elapse of certain time due to the stresses stored in the material. The specimens are crushed into the large fragments of 3 to 8 mm in the cross-section (Fig. 5). It has been established that the laser operating in the continuous mode is lacking the power for the destruction or modification of the specimens made of copper and NiCoCr alloy; these are just heated.

a

b

Fig. 5. The glass specimen destruction using the continuous-action laser

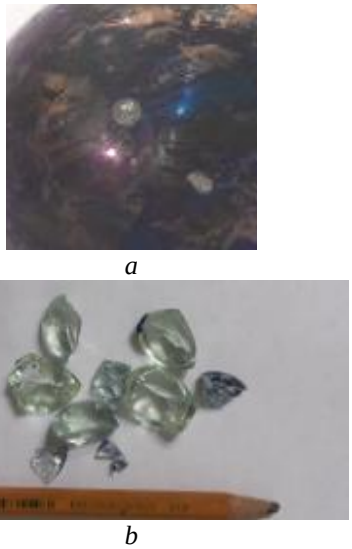
The action of pulse laser results in the melting of material or the formation of a torch accompanied by the emission of material outside away from the specimen surface. A general view of the action is given in Fig. 6 for the treated ZrO material, NiCoCr alloy and the glazed glass.



a *b*

Fig. 6. Action of the pulse laser on the ZrO material, a is a typical view of one of the holes in the specimen exposed to the action of beam with the following parameters: 5 kW, Ø 1 mm, t_{beam} =16 ms; b is the typical view of one of the holes in the specimen exposed to the action of beam with the following parameters: 5 kW, Ø 0.3 mm, t_{beam} =16 ms

The sample *a* with the initial weight of 10.47595 g and the weight after the irradiation of 10.47535 g (the difference in weight is 0.0006 g) shows a lower loss in mass in comparison with the sample *b* with the initial weight of 8.25155 and 8.24855 g after the irradiation, with the difference of 0.003 g. At a smaller diameter of the laser beam the material has not enough time to remove heat to the areas adjacent to the region of action and is subjected to the sublimation. A beam of a larger diameter causes melting with further release of material near the crater.

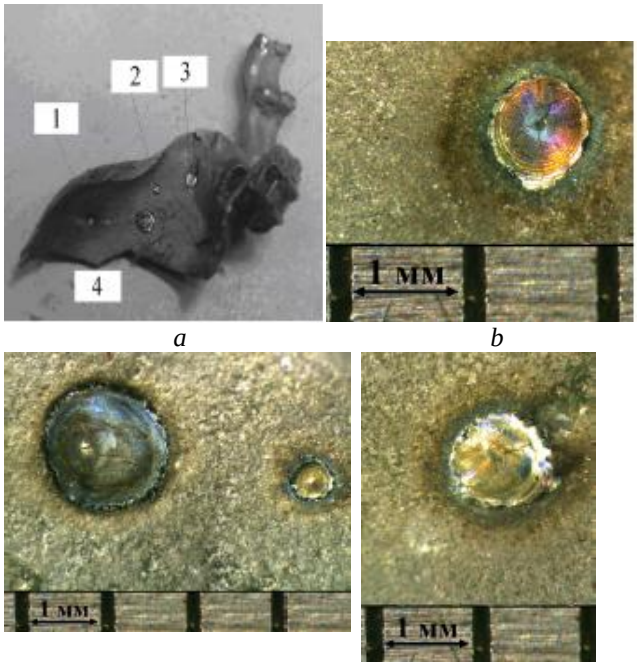


a

b

Fig. 7. A general view of the glass specimen exposed to the action of pulse laser with the following parameters: 5 kW, Ø 1 mm, t_{beam} = 16 ms

At multiple irradiations of glazed glass specimens (Fig. 7) by two to five pulses with laser beam parameters: power of 5 kW, the beam diameter of 1mm, the pulse duration of 16 ms the destruction character was similar to that of the laser operating in the continuous mode. However, the specimens were destructed faster when laser beams were irradiating them at a short span from each other in comparison with the beams focused on one point. Two pulses suffice to destruct the specimen with the diameter of laser beam equal to 1 mm and in the case of the beam diameter equal to 0.3 mm four or five pulses were needed.



a *b*

c *d*

Fig. 8. Action of the laser on NiCoCr: a – A general view of the specimen exposed to the irradiation; b is the trace of the beam No1 with the parameters 100 W, Ø 1.1 mm, t_{beam} = 16 ms; c is the traces of the beams No2 and 4 with the parameters of 1 kW, diametr of laser ray is equal to 1 mm, t_{beam} = 16 ms and 5 kW, Ø 2 mm, t_{beam} = 16 ms, accordingly

A diameter of the channels formed in the NiCoCr body due to the ablation varies from 0.5 to 1.5 mm depending on the radiation power and the beam diameter. The channels have a circumferential shape, in some cases these elongate and acquire an oval shape. At exposure to 100 W, pulse (1) the film of NiCoCr evaporated in the form of Newton rings was formed on the channel surface.

The darkening around the channels on other specimens could have been caused by ablation processes, in particular by the expulsion of evaporated substance from the channels and its further cooling and the deposition around them.

It can be seen that the action of pulse laser somewhat differs from that of electrohydraulic pulse and that of the method of pressing. In this case we observe the local heating of material, its melting and the evaporation (see Figs. 6,a,b; 7,a, and 8). These pictures show that pulse lasers with the power of more than 1 kW can be used as the sources capable of evaporating the materials that simulate the radioactive nuclear waste. Afterwards, the obtained evaporated material is

converted into the state suitable for further magnetoplasma separation.

CONCLUSIONS

Three methods used for the grinding of materials that simulate the radioactive waste have been compared. In the case of electrohydraulic pulse method about 10 to 20% of energy input into pulse is spent for the shock action that results in the destruction, the rest of energy is converted into other types of energy. This method can be used for the destruction of radioactive waste straight in the liquid cooling fuel elements. A method of static compression can provide the production of 100% of material in the fine-sized phase with the particle size less than 1 mm. However, this method is realized remotely and it will require the robotization to transfer the material to be grinded to the magnetoplasma separator. The laser operating in continuous mode destroys the materials given in the paper; however their sizes fail to meet the requirements to be used for further separation reprocessing. This method is used at the multiple exposures of destroyed specimens to the radiation. The pulse laser action allows us to obtain materials with the size less than 1 μm and in the dropwise phase the material can be represented by molecular and atomic clusters.

The offered methods allow for the production of the particles of materials that simulate RAW with the size of 100 μm. This can provide the efficient evaporation of fission products at a short-time heating during 1 to 10 s up to 2000 °C. The obtained material can be converted into the plasma state in the magnetoplasma plants.

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ИЗМЕЛЬЧЕНИЕ МАТЕРИАЛОВ, МОДЕЛИРУЮЩИХ ОЯТ ДЛЯ МАГНИТОПЛАЗМЕННОГО РАЗДЕЛЕНИЯ

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Рассмотрены три метода измельчения материалов, моделирующих твердое ОЯТ: подводными искровыми разрядами, статическим сжатием и лазерным распылением. Сравнение методов проведено посредством определения размеров полученного материала. Предпочтительными являются статическое сжатие и импульсное лазерное испарение.

ПОДРІБНЕННЯ МАТЕРІАЛІВ, ЩО МОДЕЛЮЮТЬ ВЯП ДЛЯ МАГНІТОПЛАЗМОВОГО РОЗДІЛЕННЯ

Д.В. Вінніков, М.А. Шульгин, В.В. Катречко, В.Б. Юферов, В.І. Соколенко, В.І. Ткачов, А.М. Пономарьов, І.В. Буравілов

Розглянуто три методи подрібнення матеріалів, що моделюють тверде ВЯП: підводними іскровими розрядами, статичним стисненням і лазерним розпиленням. Порівняння методів проведено шляхом визначення розмірів отриманого матеріалу. Переважними є статичне стиснення та лазерне випаровування.