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Experimental studies of porous composites destruction under electron beam high power impact

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Abstract. Studies of constructional material behavior under pulse power densities are very important both for fundamental researches and different applications. Modeling of shock wave generation in porous composites is complicated task because of complex structure of such materials. It is necessary to have rather detailed experimental database for verification of these models. In this paper, we present experiments that were carried out on high current electron accelerator "Calamary". We investigated the surface plasma expansion and mechanical kick pulse dependence from different energy fluxes. Also irradiated targets were investigated by electron microscope.

1. Introduction

Over the last years porous composites are often used as construction materials for aircraft and space industry. So it is necessary to predict behavior of such materials under high power energy fluxes for the extreme accident. Modeling for these materials is very difficult because of its complex structure. Also developing models should be verified by experimental data. There have been done many experimental investigations for different materials in various conditions [1–3]. In our work we carried out experimental study on porous composites destruction under high energy impact on the facility providing fluxes in the range 10–10^3 J/cm^2 for electron energies of 120–350 keV [4]. Beam duration is 100 ns. In our experiments we irradiated porous composite targets. The electron range in these materials was at least 1.5 mm. In the hole of irradiated targets volume explosion was observed. The beam current was measured by noninductive shunt, the electron energy was calculated from measured diode voltage, the square of energy output was measured by hard x-ray pinhole camera for high energy radiation [5]. Plasma expansion was registered in visible range by streak camera.

2. Experimental setup

Experiments were carried out on Calamary electron accelerator [4]. Voltage impulse on the diode was formed by the double water line with the electric length of 70 nanoseconds loaded from the Pulsed Voltage Generator.

Because of porous structure in the main part of experiments we provided energy flux 10–100 J/cm^2 for electron energies about 150 keV. Also there were implemented a few shots with

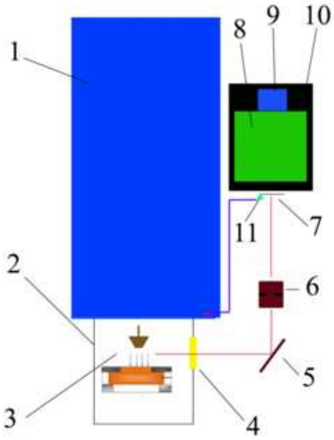

Figure 1. Scheme of the experiment: 1—Calamary accelerator, 2—vacuum chamber, 3—diode, 4—optical window, 5—mirror, 6—long-focus lens with variable aperture, 7—camera input slit, 8—electron-optical camera SFER-6, 9—image registration system, 10—electro-magnetic shield, 11—fast LED.

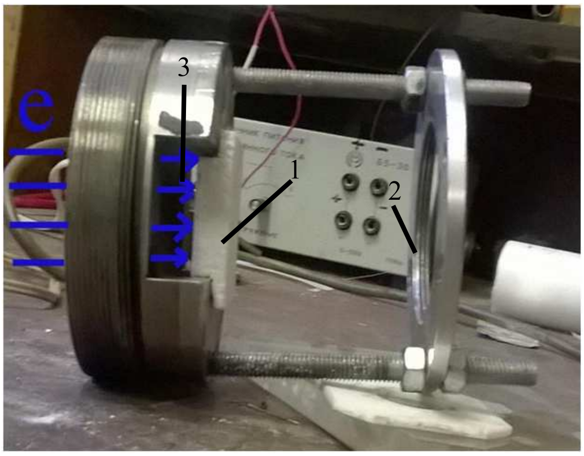

Figure 2. Anode unit: 1—target; 2—pinhole-camera holder; 3—observation window.

electron energy $\geqslant 250$ keV and energy flux $\geqslant 200$ J/cm^2 which demonstrated open destruction of the target. In all experiments current impulse duration on FWHM was about 100 ns. Anode targets were produced from porous composites with density 0.1–0.8 g/cm^3.

The beam current was measured by noninductive shunt, the electron energy was calculated from measured diode voltage, the square of energy output was measured by pinhole camera for high energy radiation [5]. In some experiments we measured electron range in the target be the pinhole camera situated perpendicular to the beam axis. The mechanical kick impulse was measured by the detector based on piezoelectric vibration sensor [5].

Anode plasma expansion was registered in visible range by streak camera SFER-6. Registration optical scheme is presented on figure 1. Synchronization of expansion image with beam current was provided by fast LED energized from additional output of the current shunt.

For diode gap observation we developed special anode unit with wide window and pinhole-camera holder (figure 2).

The targets were fixed in the anode unit by special frame with the aperture on the axis for the measurements of the energy flux corresponding to the spallation strength edge.

3. Experimental results

In the first experimental series the beam of the electrons with the energy up to 150 keV provides power density on the target 35–120 J. Beam-target interaction aria was primarily circled with the diameter from 7 to 15 mm. The example of beam current and electron energy are presented on figure 3a. The beam power is presented on figure 3b.

Back split-off was observed at energy fluxes near 180 J/cm^2 (figure 4). Sideways view demonstrates that the explosion and matter expansion was not only on the surface but also in the target depth. The shape of the crater on the front side is spherical.

There were carried out investigation of crater surface and inner structure of irradiated targets by electron microscope. Microphotographies are presented on figure 5. On crater surface we can see sintered mass of the target material (figure 5a). It means that the temperature of the

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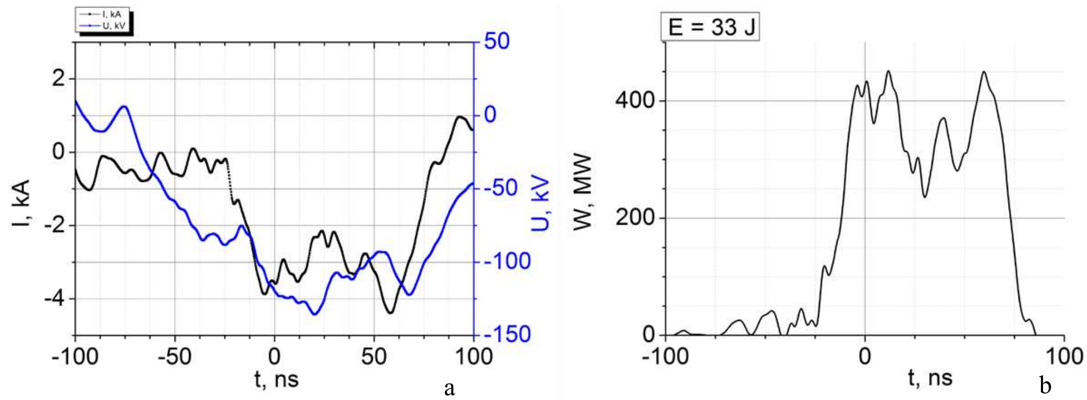

Figure 3. Measured beam parameters: (a)—current and resistance voltage; (b)—power on the target.

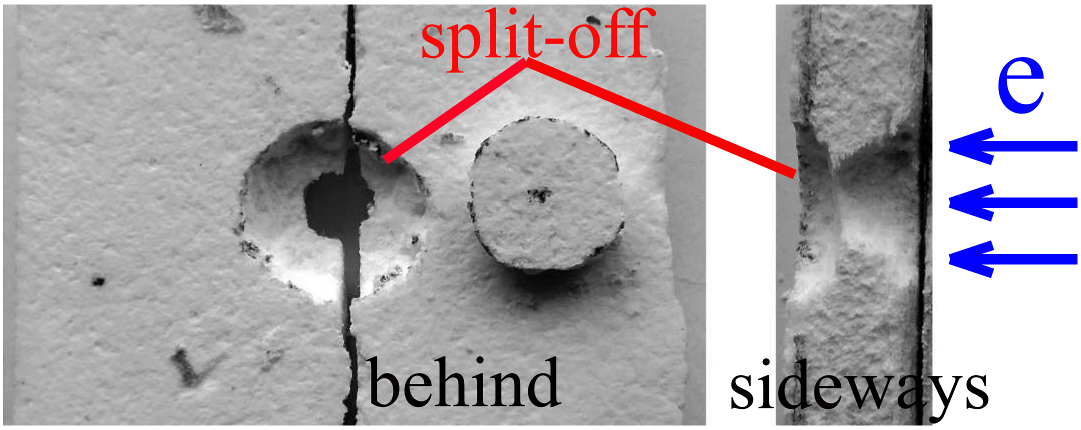

Figure 4. Irradiated target with backside split-off.

surface is very big. But in the depth of the target (figure 5b) we observe destructed fibers without melting ablation.

Also expansion dynamics was investigated for this energy range. It's very difficult tusk for this regime to synchronize the work of the streak camera with the beam current because the EMI is still very high but the main synchronization signals are very low. The imagine of plasma expansion is presented on figure 6a. The plasma velocity was determined as a decline of constant brightness line. Red lines define the ranges oa permanent velocity. We can see that the velocity of plasma expansion falls down after anode and cathode plasma flows colliding. Experiments on expansion velocity measurement for high energy fluxes (160 J/cm^2) demonstrated the velocity variation during expansion (figure 6b). It could be concerned with rather big electron range in pourous materials and specific field structure.

The detector for the mechanical kick impulse measurements was calibrated with the porous composite targets because its behavior under fast kick is very different from polymeric materials. Experimental results presented on figure 7.

The dependence of kick pulse from energy flux for porous composites is similar to the dependence for polymers (linear growth).

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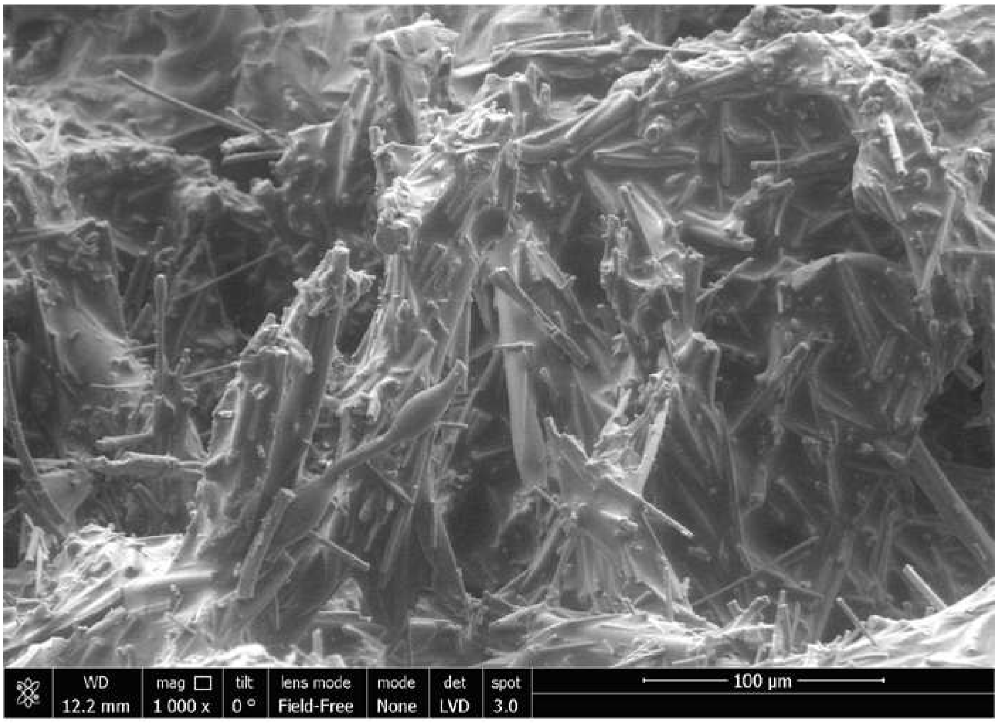
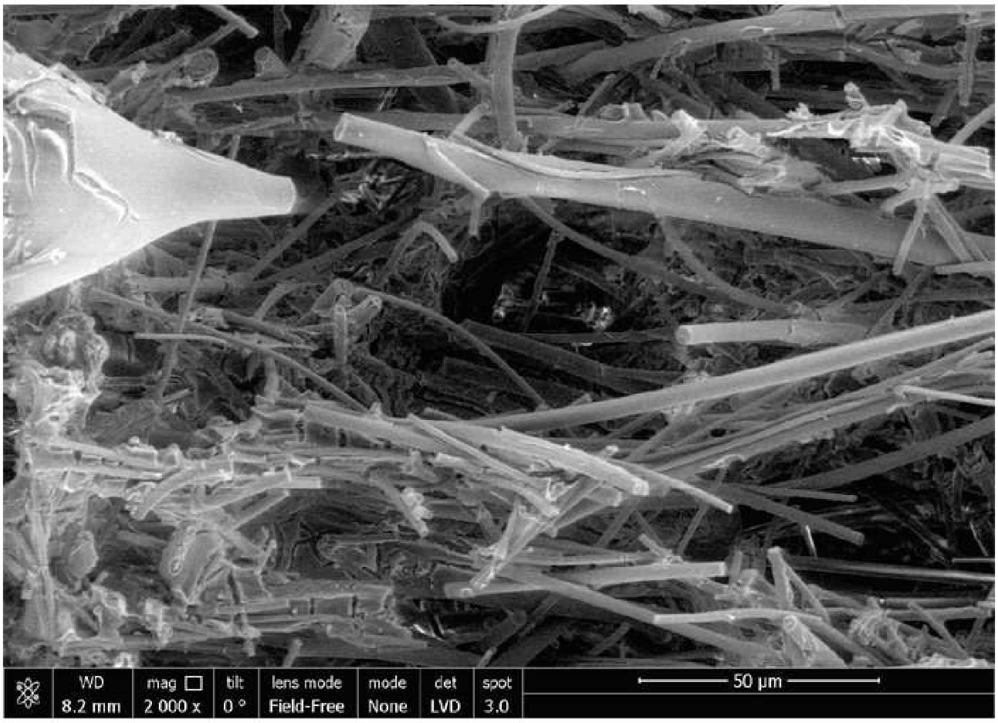


a



b

Figure 5. Microphotographies of irradiated target: (a)—crather surface; (b)—target depth.

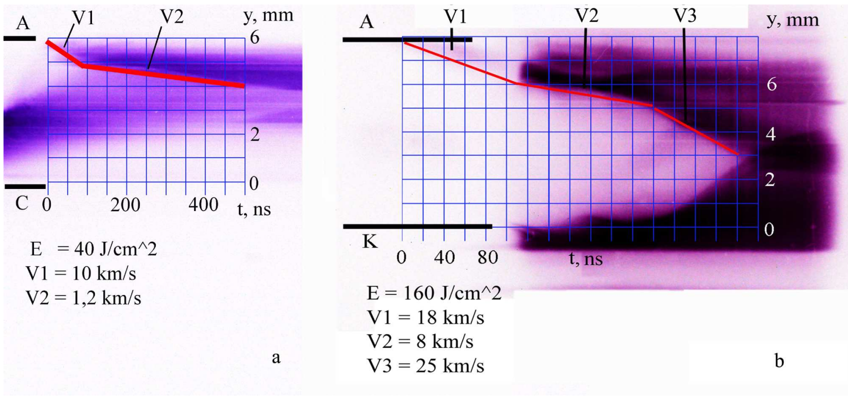


Figure 6. Plasma expansion at low (a) and high (b) energy flux: A—anode; K, C—cathode.

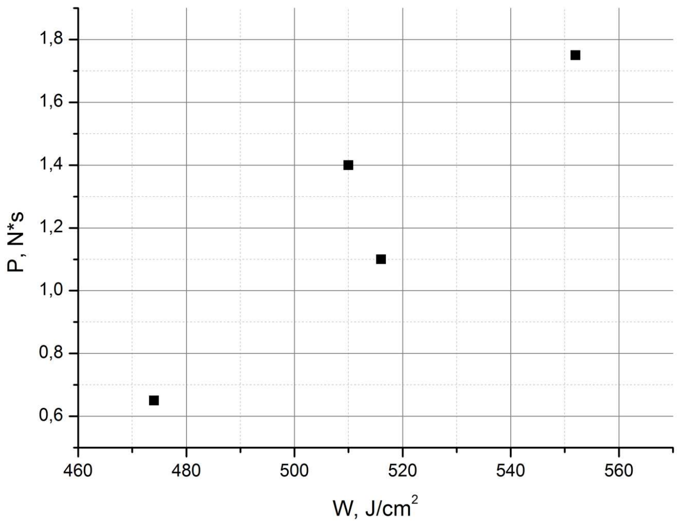


Figure 7. Mechanical kick impulse dependence from energy flux.

4. Conclusions

The investigation of porous composites destruction under high power electron beam impact demonstrated following phenomena of its behavior: porous structure seems to provide large electron range ($\geqslant$ 1 mm) leading to the explosion in the target depth and hard shockwaves attenuation. Large electron range provides rather slow plasma expansion on the first stage. Plasma flows from the depth of the target and surface layers lock it. Nevertheless, expansion velocity values (10–25 km/s) are closed to values for polymeric targets expansion for similar energy fluxes. Porous structure also seems to provide rather big target matter mass ablation. It was impossible to measure ablated mass because the targets were hardly destructed after the shot. Hard shockwaves attenuation and big ablated mass appear that the kick pulse for these targets is twice more than for polymeric one.

Acknowledgments
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References
[1] Bushman A V, Efremov V P, Kanel G I, Lomonosov I V, Utkin A V, Fortov V E and Yushkov E S 1992 *Khim. Fiz.* **11** 410–414
[2] Bushman A V, Lomonosov I V, Fortov V E and Khishchenko K V 1994 *Khim. Fiz.* **13** 64–81
[3] Demidov B A, Efremov V P, Kalinin Y G, Petrov V A, Tkachenko S I and Chukbar K V 2012 *Tech. Phys.* **57** 405–409
[4] Demidov B A, Ivkin M V, Petrov V A and Fanchenko S 1979 *At. Energy* **46** 111–116
[5] Demidov B A, Efremov V P, Kalinin Yu G, Kazakov E D, Metelkin S Yu, Petrov V A and Potapenko A I 2015 *J. Phys.: Conf. Ser.* **653** 012009