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
ergy impact on the facility providing fluxes in the range 10–10³ J/cm² 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/cm² for electron energies about 150 keV. Also there were implemented a few shots with...
electron energy \( \geq 250 \text{ keV} \) and energy flux \( \geq 200 \text{ J/cm}^2 \) 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 by 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 area 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
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 task 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 of 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/cm²) demonstrated the velocity variation during expansion (figure 6b). It could be concerned with rather big electron range in porous 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).
Figure 5. Microphotographies of irradiated target: (a)—crater surface; (b)—target depth.
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 ($\geq 1$ 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.
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