A pilot study of the behavior of structural materials under powerful pulse influence on the “Calamary” accelerator

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Abstract. The first studies of two types of structural materials of plasma systems under the influence of a high-current electron beam at the Calamary installation were carried out. Beam exposure parameters close to the emergency modes of some types of plasma systems are selected.

1. Introduction

In emergency situations in high-power plasma installations, a powerful pulsed action of plasma or charged particle beams (see, for example, [1-3]) with a total energy release of up to tens of J/cm² and very significant power fluxes can occur on the wall of the vacuum chamber or protective structures. In this work, for experimental modeling of such situations, it is proposed to use the Calamary high-current electron accelerator, which was previously used to study the resistance of polymer and composite materials to powerful ionizing radiation fluxes. The main element of the Calamary accelerator is a double forming line (DFL) with an electric length of 70 ns, charged from a pulse voltage generator.

The advantage of this setup is that it is equipped with a fairly wide range of diagnostics, which make it possible to accurately register the level of exposure and the influence of various factors [4]. The diagnostic complex of the setup can be divided into two main parts: diagnostics of beam parameters and a complex of optical diagnostics for studying plasma and shock wave processes, as well as destruction of samples. To determine the beam current, a low-inductance foil shunt is used, located in front of the entrance to the diode assembly. The voltage in the diode gap is determined by the readings of the high voltage divider located at the output of the DFL taking into account the inductance of the anode assembly. The region of interaction between the beam and the target is estimated using a pinhole camera with an extended dynamic range [5]. Also, the process of interaction between the beam and the sample is controlled using a calibrated X-ray dosimeter, which records the progress of the power of the X-ray bremsstrahlung. The optical diagnostic complex allows one to detect plasma expansion in its own light [6], as well as using shadow and schlieren photography methods. Image registration is carried out using streak-camera. Also, using shadow methods, one can...
investigate spallation processes on the back surface of the samples under study. In addition, the possibility of studying the propagation of shock waves in a laser shadow is realized for transparent materials [7].

For a pilot study of the applicability of the accelerator to study the resistance of plasma materials under a powerful electron beam, two main structural materials were chosen. Reduced-activation ferritic-martensitic (RAFM) steels is a promising structural material for the vacuum chamber and in-chamber components of the tokamak. Tungsten is a tokamak divertor material subjected to the highest energy loads.

2. Experiments

In the study, samples of 10x10 mm$^2$ in size from polycrystalline tungsten (Goodfellow) and ferritic-martensitic corrosion-resistant steel EK-181 (Rusfer) were irradiated with an electron beam of electrons from the Calamary pulse accelerator. The accelerator was tuned to a low-energy beam mode, providing a voltage in the diode gap (and, accordingly, electron energy) of up to 200 keV. The average range of electrons in the samples under such conditions did not exceed 100 μm, and the main energy was released in a layer much smaller in thickness. Samples were mounted in a hole located in the center of the anode plate on a metal substrate. The diode gap was approximately 10 mm. In the experiments, standard cathodes used at the Calamary installation were used. The cathodes were made of brass in the form of a truncated cone with a conical hole along the axis ("fish mouth"). The total energy release in these experiments did not exceed 100 J / cm$^2$. For each sample, 1 “shot” was fired. Figure 1 shows the course of current and voltage in vacuum diode and power released in the surface layer of the samples.

![Figure 1. Electron beam parameters for ferritic-martensitic corrosion-resistant steel EK-181 (a) and polycrystalline tungsten (b).](image)

Total shot energy for steel and tungsten samples was 60 J and 80 J respectively.

Figure 2 shows photographs of irradiated samples. It can be seen that the samples of steel undergo a much greater destruction, and microcracks are supposedly observed on the surface in addition to
drops of boiling material. For a more detailed study, steel samples were examined using an optical microscope with high spatial resolution.

Figure 2. Irradiated samples of ferritic-martensitic corrosion-resistant steel EK-181 (a) and polycrystalline tungsten (b).

Microscopic studies (Figure 3) demonstrated thread melting of the sample surface and confirm the presence of some microcracks up to 50 mkm length. The appearance of cracks on a steel sample can be explained by the relatively low thermal conductivity of this material (about 20 W/m\(\times\)K). At the same time, traces of foreign deposited material were found on the surface. Presumably this is cathode material. In this regard, for further studies it is proposed to use cathodes of a more refractory material (Mo, W).

Figure 3. Microscopic photography of steel EK-181 sample in different scales. The arrow indicates the position of the microcrack.

3. Conclusions

An approach has been tested to simulate the effects of powerful energy flows on structural materials using a high-current electron beam. At relatively low integral impact energies, areas of uneven boiling, and possibly sublimation of the material, are observed (both for steel and tungsten).

It is necessary to maximize the uniformity of the beam by distributing it over the entire plane of the sample, for which it is planned to use flat cathodes made of more stable materials (W, Mo).

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