Research of igdantine destruction under high-current beam of electrons with energy more than 1 MeV

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Abstract. Research of the composite materials destruction under extreme pulsed loads is an important task, both for different materials science applications and development of a fundamental understanding of the formation and propagation of shock waves in materials with a complex internal structure. In this paper, we present an experimental study of the interaction of a high-current electron beam with a low-modulus polymer material characterized by high elasticity. It has been demonstrated that this effect also causes multiple cracks in the peripheral regions of the sample (~10 mm in length).

1. Introduction
Previous researches of polymeric materials under the powerful energy fluxes demonstrated that substances similar in mechanical properties (density, spall strength, Grüneisen coefficient) in similar conditions (fluence) can demonstrate a substantially different picture of failure (see, for example, [1, 2]). The latest studies have shown that at different depths of the energy release region, mechanical effects can also be very different even for the same material [3]. In this paper, we propose an experimental study of the strength properties of igdantine under the powerful pulsed electron beam providing volumetric energy release in the thickness of the material. The low modulus polymeric material, igdantine, consisting of gelatin, glycerol and formaldehyde, which is actively used in the study of the properties of thin-layered composites [4], is highly elastic, and therefore damageable under surface impact even at sufficiently high pressures. The experiments were carried out on a powerful high-current electron accelerator RS-20, providing a current in the diode gap of up to 100 kA at a peak voltage of up to 1.5 MV and a total pulse duration of not more than 500 ns. At electron energies of more than 1 MeV, the average range of electrons in light polymers can exceed 5 mm. In this conditions, volumetric energy release takes place, which has a significant effect on the formation of shock waves. This effect was demonstrated in [3] upon irradiation of samples from plexiglas and polystyrene. It should be noted that the character of the formation of a shock wave can be affected not only by the range of electrons, i.e. the depth of the energy release region, but also the fact that the process is isochoric, due to the short duration of the process (the shock wave does not have time to take the material beyond the boundaries of the energy release region during the beam action).
2. Experimental setup
The sample produced from igdantine had cylindrical form with star-like cavity on the axis. The cylinder was cut in half along the generatric lines (figure 1). It was placed on the anode plate of RS-20 facility.

![Sample produced from igdantine](image1)

**Figure 1.** The sample produced from igdantine.

The convex surface of the sample looked to the cathode, and accordingly, to the electron beam. This provided the maximum of sample elasticity to mechanical action. The output chamber of the generator was constructed for the "beam" regime [4], providing the possibility of visual observation of the irradiated object. The gap between the cathode and the surface of the sample was 30 mm. The scheme of the experiment is shown on figure 2.

![Experimental scheme](image2)

**Figure 2.** Experimental scheme. 1 – cathode, 2 – anode, 3 – sample, 4 – electron beam.

3. Experimental results and discussion
In this configuration, due to the presence of a dielectric in the diode gap, the electric field is substantially distorted, which leads to the fact that the operation mode of the installation is not optimal, the beam formed is not sufficiently stable, and electrons energy is not maximal. In our experiment, it led to a tightening of the current pulse to almost 500 ns. The time variation of the current and voltage is shown in figure 3.
Figure 3. Temporal dependence of the diode current and voltage.

It is noteworthy that the current and voltage fronts are rather sharp. This leads to the fact that the maximum of the spectral distribution of the electrons is shifted closer to the region of the maximum energy - 1 MeV. It means that the average range of electrons in the sample is very close to 5 mm. On figure 4 shows a sample of idgantine exposed to the electron beam of the RS-20 installation.

Figure 4. Irradiated sample.

The through-burning depth of the sample was almost 4 times deeper than the average electron range in the sample. It is also worth noting that, due to the low conductivity of the material, some electrons "get stuck" in its thickness and create a very substantial space charge. The accumulation of
such volumetric charges leads to electrical breakdowns, the traces of which due to the high transparency of the material are observed at the surface of the sample in the form of Lichtenberg figures (figure 4). Taking into account the deceleration effect of the electric fields of the sample on the electron beam propagation in the dielectric, we should expect a decrease in the penetration depth of electrons into the iodantime.

On the other hand, a high-intensity electron beam impact is accompanied by the generation of high-amplitude shock waves capable of causing spalling of the sample. The experimental results (see figure 4) demonstrated the formation of multiple cracks in the peripheral regions of the sample (~ 10 mm in length). It should be noted that in experiments in which a pressure of up to 350 Pa · s and a duration of 3 μs was formed by the electric explosion of foil, which is comparable with the parameters attained in the focal spot of the beam, macrocrack formation was not observed. The difference between the pressure created during the electric explosion of a foil and the electron beam impact is characterized by the volume contribution of energy to the sample.

Polymeric materials are characterized by a sufficiently low temperature of the onset of decomposition. Experiments on the thermal degradation of iodantime were carried out by differential scanning calorimetry. Conducted experiments showed that when heated in a sealed crucible at a rate of 1 K/min the loss of mass begins at a temperature of 220°C. In this case we observed releasing of a heat in iodantime. At a temperature of ~ 350°C the mass loss reaches 30% and further decomposition occurs with the absorption of heat, which is typical for the evaporation of the material. The complete decomposition of iodantime occurs at a temperature of 400°C, but a condensed phase is not formed.

It should be noted that there are no traces of soot formation in the area to the electron beam exposure. The structure of the region of burning of iodantime is not characteristic for shock-wave destruction, but more corresponds to the gas-dynamic drift of a sample with a high exhaust velocity. Similar effects are well known in the electrical breakdown of polymer and energy materials [5, 6]. In the latter case, the formation of radial cracks occurs when the tangential stresses exceed the tensile strength. Low acoustic stiffness of the iodantime indicates that the destruction can be determined to a decisive extent with the influence of mechanical loads, formed from the formation of gaseous products of thermal decomposition.

Thus, an analysis of the character of degradation of iodantime by an electron beam of the RS-20 accelerator indicates that it is the rapid kinetics of the thermal degradation of iodantime with the formation of gaseous decay products that is largely responsible for the observed effect of sample destruction at great depth.

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