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FAILURE OF A CADMIUM FOIL UNDER INTENSE X-RAY RADIATION

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In this paper, we report on the results of a study of the failure of cadmium samples under x-ray radiation produced by a nuclear explosion. Critical loads that cause macroscopic spall fracture, generation of spall microcracks, and removal of the material from the surface are determined.

Cadmium coatings are used in various structures in nucleonics, because they are corrosion-resistant and protect from penetrating radiation. In this connection, the study of the limiting resistance of thin cadmium layers under severe radiation conditions is of both practical and fundamental interest. The object of this paper is to study this problem for the conditions of intense x-ray radiation produced by a nuclear explosion.

Test samples were cut from a 0.30-mm-thick cadmium foil as disks 20 mm in diameter. A sample was housed in a special casing so that its rear surface was supported by a low-density polystyrene foam layer, while the surface exposed to nuclear explosion was screened by a cadmium shield. To control the reproducibility of results, we placed two identical casings with samples at equal distances from the radiation source. Upon exposure to radiation, the casings with samples, which remained intact to a large extent, were inspected visually. The structure and character of fracture of the samples were studied by metallographic analysis.

Fragments of a longitudinal section of one sample are shown in Fig. 1 with a magnification of $\times 100$ (a) and $\times 500$ (b) diameters. In the first case, one can observe the formation and opening of a macroscopic spall crack. In the second case, the structure of the cadmium sample and the character of microscopic spall fracture are more evident. The same pattern takes place for the other sample. In particular, the measurements performed show that the material from the sample surface was removed to a depth of about 0.02 mm. The thickness of the spall layer was about 0.05 mm, while spall macrofractures appear as pores at a depth of about 0.10 mm.

Figure 2 shows the profile of the absorbed energy E across the sample thickness obtained in numerical calculation. The x-ray pulse duration was significantly shorter than the time of passage of an acoustic wave through the sample. This made it possible to ignore the pulse duration in preliminary consideration of physicomechanical phenomena occurring under loading. The cadmium characteristics were taken mainly from [1]. The initial temperature of the sample was about 20°C. To go over from the absorbed-energy profile to the profile of the heating temperature ΔT, we used the mean heat-capacity value of 248 J/(kg · K) for the temperature range of 20–320°C. In this case, the heating $\Delta T = 300$ K, which corresponds to the onset of the transition from the crystalline to molten state, was realized for $E = 75$ kJ/kg, i.e., at a depth $x = 0.06$ mm. The complete-melting conditions, which require $E = 132$ kJ/kg, were not attained at the sample surface; therefore, the surface layer 0.06 mm thick heated to 300 K remained in the solid, although unstable state. Thus, at the characteristic fixed depths, the temperatures that correspond to the removal of the material from the surface ($x = 0.02$ mm), generation of spall microfractures ($x = 0.10$ mm), and complete macroscopic spall failure ($x = 0.25$ mm) were 321 (melting point), 228, and 141°C, respectively.

From the results on the heating of the sample, one can evaluate the negative tensile pressure at a depths that correspond to the generation of microfractures and macroscopic spall fracture and also estimate roughly the negative pressure at depths that correspond to the removal of the material from the surface. For

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Fig. 1

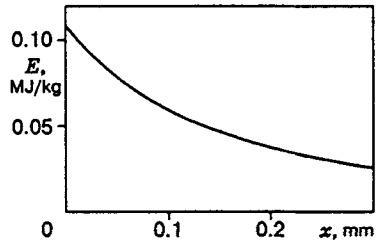

Fig. 2

this, simplifying the situation, we represent the heating-temperature profile across the thickness of the sample by the exponential function $\Delta T = 300\,e^{-3.64x}$, using points on the surface and at a depth of the macroscopic spall fracture as reference points.

One easily obtains a solution of the acoustic problem of the wave process in the heated sample. Particular cases of the problem for the required depths x are presented in Fig. 3. In solving the problem, we used a density value of 8.64 g/cm^3 and a volume speed of sound 2.42 km/sec. The mean value of $31 \cdot 10^{-6}$ K^{-1} for the range of 20–320°C was used as the temperature coefficient of linear expansion. The time curves of the pressure P, as shown in Fig. 3, correspond to depths $x = 0.25$, 0.10, and 0.02 mm (curves 1–3). Analysis of these curves shows that loading by a tensile pulse with a negative pressure of 1.20 GPa and a duration of 0.02 μsec at 140°C results in complete macroscopic spall fracture of cadmium, whereas loading by a pulse of the same duration with a negative pressure of 0.65 GPa at 230°C leads to an early stage of generation of spall microfractures. One can also assume that the spall failure of cadmium heated to the melting point is characterized by a negative pressure of about 0.1 GPa which acts for about 0.01–0.02 μsec.

Let us compare our results on cadmium failure under x-ray radiation with the results of [2] on irradiation by a high-current electron beam. In [2], cadmium samples of various thicknesses were exposed to radiation to determine the effect of the tensile-pulse duration τ on the critical negative pressure in the initial stage of macroscopic spall fracture.

Figure 4 shows the results of the present work and of [2] (points 1 and 2, respectively). Filled points indicate preservation of macroscopic integrity of the sample, and open points indicate the formation of a visually observed macroscopic spall crack in the sample. Moreover, spall surfaces were analyzed in [2] using a computer image-processing system. The mean size of surface roughness for samples 0.18–0.30 mm thick was within 0.02–0.03 mm, which is in good agreement with the results of our qualitative analysis of the images of the diametral longitudinal section. Experimental results on spall fracture of the material heated to the melting point are presented in [3]. Under explosive loading of tin samples by shock waves of various intensity in the pressure range 16–22 GPa, the spall strength of tin was found to decrease from 0.7 to 0.05 GPa. This decrease

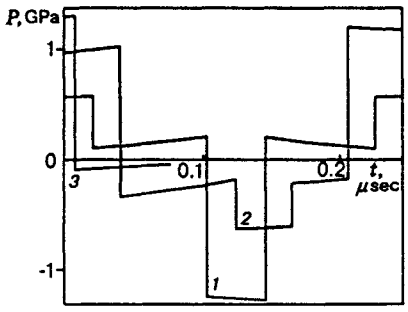

Fig. 3

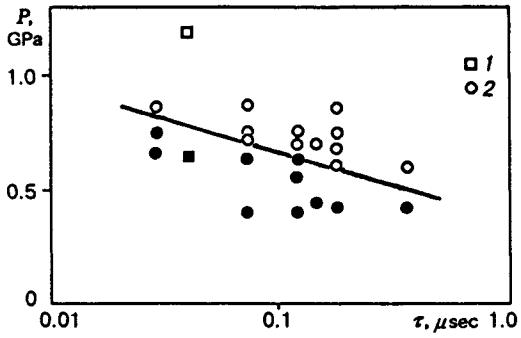

Fig. 4

is probably caused by the fact that, in this pressure range, the loaded material was imparted the energy required for the transition from the crystalline to the molten state, and the sample temperature corresponded to the melting point. In this case, the rough estimate of the conditions under which the cadmium surface layer is removed from the surface heated to the melting point can be considered acceptable.

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