INVESTIGATION OF THE MECHANISM OF DESTRUCTION OF CERTAIN POLYMERS BY A PLASMA RADIANT FLUX

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A description is given of the damage to polymer films caused by a plasma jet produced in a special discharge chamber. The results confirm the model of destruction of polymer materials by the radiant energy flux proposed in [1, 2].

The question of the interaction of radiant fluxes and solids – in particular, polymers – is of great interest. Its successful investigation depends upon a more detailed study of the actual mechanism of destruction of the material. A model of the surface and interior destruction of polymers by the combined action of convective and radiant fluxes was proposed in [1, 2], where the destruction of certain heat-degradable polymer materials in a continuous (steady-state) low-temperature plasma jet was theoretically and experimentally investigated. The velocity of the plasma jet was about 100 m/sec, and the temperature on the order of 900-11,000°K.

Our object was to test the above-mentioned model on devices of the pulsed type, in which the plasma jet velocity exceeds the speed of sound and the stagnation temperature of the plasma is tens of thousands of degrees.

As energy source we used the discharge in a capillary of the EV-39 type, whose properties are described in detail in [3, 4], where the source temperature is given as approximately 40,000°K, the pressure in the capillary as approximately 500 atm, and the jet velocity as up to 10 km/sec.

To obtain a supersonic plasma flow we used the method and the electrode arrangement described in [5]. The capacitance of the pulsed capacitor bank was 300 μF, the voltage was 1.5-2 kV, and the inductance of the discharge circuit was on the order of 1 μH. The discharge obtained is periodic and attenuating, the amplitude of the second half-period being much less than the amplitude of the first half-period (the first half-period lasted about 100 μsec). The discharge between the electrodes in the discharge chamber was initiated from the control panel of an SER high-speed photorecorder. An investigation of the selected electrical regime showed that the temperature of the plasma jet is more than 10,000°K (the plasma temperature was determined by the method described in [6]); the jet velocity, determined from the photographic records, was 7-10 km/sec.

The choice of this type of discharge as energy source was dictated by the fact that when plasma jets are decelerated at a solid barrier (surface of the specimen) the temperature of the jet increases sharply. According to certain estimates the stagnation temperature of supersonic plasma jets in a series of pulsed discharge regimes is about 50,000°K (see, for example, [7]). It is known that at such high temperatures the radiant flux is the principal component of the total heat flux.

Films composed of polystyrene, polyvinyl alcohol, high-pressure polyethylene, lavsan, kapron, teflon, and a number of other materials were exposed to the radiant flux. These films were from 50 to 300 μ thick. Both oriented and nonoriented polymer materials were investigated.

The composition of the obtained plasma was determined spectroscopically. The spectrum includes lines belonging to the material of the electrodes and the discharge chamber (the discharge chamber was usually made of textolite, plexiglas, or some other nonconducting material).

Dushanbe. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 10, No. 3, pp. 151-153, May-June, 1969. Original article submitted December 17, 1968.

The results of the experiments revealed the following.

The plasma jet acting on the surface of the film forms cavities whose depth may be as much as 80% of the total thickness of the film, while the diameter of the region of destruction varies from 8 to 14 mm or more. Moreover, material from the chamber and the electrodes is deposited on the surface of the specimen in the form of fine particles and liquid droplets. Finally, the pulse action causes sharp changes in the surface structure of the specimen.

Various inhomogeneities are formed on the surface of all the films exposed to the plasma jet. In the case of oriented materials these are accompanied by interlacing veins, and in the case of kapron by individual protuberances of various shapes and sizes. Such veins are not formed on the surface of nonoriented materials. In this case a distinctive random picture is observed.

On the basis of the microphotograms it is possible to distinguish two types of damage: surface and interior. For most materials both types of damage may be simultaneously observed. Surface damage is illustrated in Fig. 1, which shows the surface of a kapron film 75 μ thick. The picture was obtained in the center of the region of destruction, where the jets were directed strictly at right angles to the film surface. Clearly, a system of surface gas bubbles has been formed as a result of the action of the plasma jet; the diameter of the bubbles in Fig. 1 varies from 10 to 45 μ (magnification 270 ×). Thus, the nature of the surface damage differs from the same material according to its structure. However, it should be noted that this description is still preliminary in character.

To clarify the mechanism of destruction in the interior of the investigated materials we obtained thin sections of certain specimens. An investigation of these sections showed that near the surface of all the films investigated the pulsed discharge creates a carbonaceous layer, whose thickness varies according to the material. Beneath this layer gas bubbles are formed in the undecomposed part of the material. Depending on the nature of the material these bubbles are formed at various depths within the film and have various sizes.

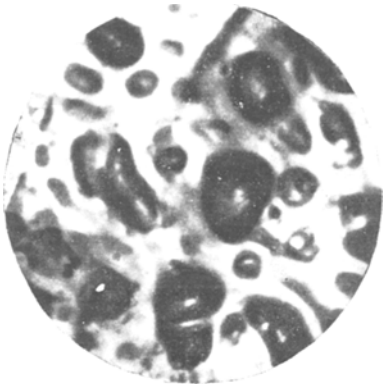

Fig. 1

A microphotogram of a thin section of a teflon film 250 μ thick is shown in Fig. 2a (magnification 600 ×). Clearly, a carbonaceous layer 8-10μ thick can be distinguished at the surface of the specimen. Beneath this layer there is a gas bubble approximately 25 μ in diameter.

A thin section of a kapron film is shown in Fig. 2b at the same magnification; in this case the thickness of the carbonaceous layer was 5-6 μ. The gas bubble in Fig. 2b measures 35-155 μ. We note that, as distinct from the results of [1, 2], the shape of the bubbles is noticeably nonspherical. This is evidently a consequence of the intense pulse action on the material when the plasma jet is decelerated. The origin of the gas bubbles was discussed in [1, 2], where it was shown that the radiant flux, penetrating into the specimen, causes breakage of the chemical bonds in the polymer molecules, as a result of which

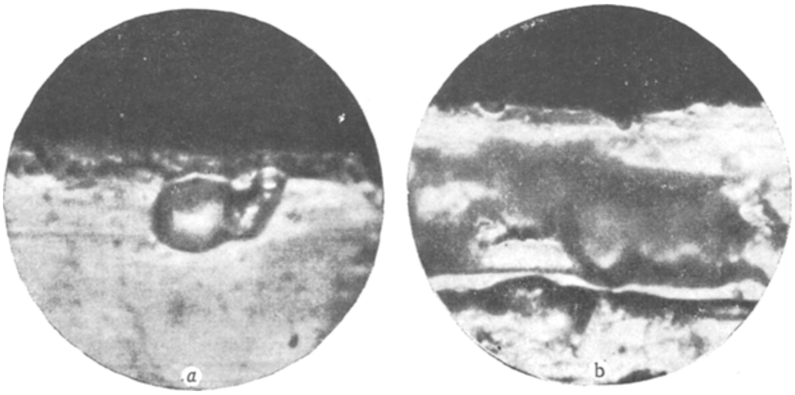

Fig. 2

cavities filled with gaseous decomposition products are formed. The gas pressure in these bubbles is very high; it causes the appearance of cracks connecting the bubbles with each other and the surface of the material.

Thus, we may conclude from an analysis of the microphotograms that in this case the principal role is played precisely by the radiant energy flux. The following considerations serve as additional confirmation of this assumption.

In [8] it was shown that materials that do not melt in a pulsed discharge and are not decomposed by radiant energy quanta are almost undamaged by a pulsed plasma jet (carbon, wood, textolite, etc.). Even a sheet of writing paper can withstand several plasma pulses without suffering appreciable damage. For example, in [8] the surface of a tungsten plate was covered with a sheet of writing paper, nontransparent for the plasma radiation, out of which a star shape was cut. The action of the supersonic jet severely damaged the exposed area of tungsten, while the paper remained almost intact. Moreover, the metallic surfaces of soft metals were protected from the action of plasma jets by means of water and oil. It was shown that although the mechanical impuse severely bent the sheets, their surface remained quite undamaged.

As a final verification of the model proposed in [1, 2] we conducted certain additional experiments. The film specimens were placed under a sheet of plexiglas up to 1 mm thick and subjected to the action of a pulsed discharge under more severe conditions. By means of an x-ray structural analysis and infrared spectroscopy it was shown that the supersonic plasma jets produced certain changes in the structure of the materials of the same type as in the unprotected specimens, although there were no signs of damage on the surface of the specimen.

Considering that plexiglas is almost transparent for the plasma radiation, we may assume that the radiant energy flux does, in fact, play the principal role in the mechanism of destruction of polymer films by supersonic plasma jets.

Thus, the model proposed in [1, 2] is also valid for pulsed plasma sources. Additional experiments are required before the mechanism of destruction of polymer films by supersonic plasma jets can be satisfactorily explained.

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