Therefore, conductor shaping can substantially reduce the loss of flux by diffusion and considerably improve the performance of a CM generator. There are two reasons for this: first, the shaped conductors allow one to provide a given λ with a shorter generator, which reduces the working time and thus reduces the flux loss; and secondly, the field in such a generator is inhomogeneous: it is large near the point where the conductors meet and weak in the rest of the generator. This field distribution means that the flux losses in the wide part and in the load can be neglected for almost all the flux compression time, with only a minor correction for the small zone near the junction and also for the short period required to compress the field in this zone. Of course, the specifications for the contact in that case are very much more severe, since even minor irregularities on the conductors result in trapping the strong field and thus large contact losses.

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DAMAGE PRODUCED IN GLASS BY METEORITE IMPACT

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UDC 523.51

The effects of meteorites on transparent brittle materials are important in long-term operation of optical systems in space, such as windows, solar-battery coatings, and so on. Since the material is brittle, the damage on impact differs from that for a plastic metal.

Exposure of specimens in space shows [1] that the surface damage is particularly important, since the probability of encountering a large particle is low. Sometimes, however, interest attaches to the possibility that the specimen will be entirely destroyed. Studies have been made [2] of the effects of particles of micron size on glass and quartz for particle masses m of approximately 10^{-10}–10^{-12} g traveling at speeds v of 2-14 km/sec. Data are available only from isolated tests [3] for larger particles, so it is desirable to compare [2] with a fairly wide range of evidence for large particles in order to elucidate the scope for scale simulation and also to refine our picture of the process.

The present experiments were performed under laboratory conditions by means of explosions [4]; we used spherical steel particles accelerated to v = 5-12 km/sec and having diameters d = 0.7-2.3 mm (m ~ 10^{-3}–$5 \cdot 10^{-2}$ g). The specimens were glass disks (optical crown glass) with polished surfaces; a specimen was attached to a metal holder by a flat clamp at the edge acting via a damping ring; the side surface remained free, while the diameter was 115-255 mm, having a thickness δ of 8-20 mm. For comparison, several tests were performed with quartz specimens. The system prevented the explosion products from affecting the specimen; it was not necessary to ensure that the particles struck the center of the disk. A few experiments were done with particles in the range d = 0.1-0.3 mm (m $\sim 3 \cdot 10^{-6}$– 10^{-4} g), which were accelerated in a vacuum chamber to 5-13.5 km/sec, the final size being determined within ± 10%. In addition, measurements were made with glass particles.

Figure 1 shows a photograph of a specimen of diameter 115 mm and δ = 15 mm after the experiment (d = 0.75 mm and v = 10 km/sec for the particle). A radial ringed structure in the cracks is clear, and this is the same for any speed of impact. The diameter of this zone is $D \gg d$, and is close to the sizes observed on impact on rocks [5, 6], but in the case of glass the material is ejected only from a central part of size D_1

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 4, pp. 127-130, July-August, 1976. Original article submitted September 1, 1975.

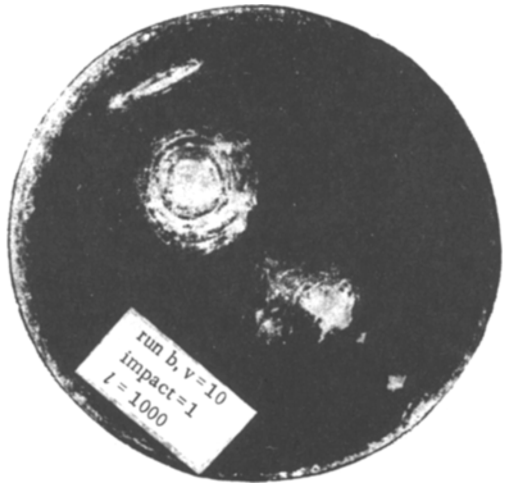

Fig. 1

TABLE 1

v, km/sec	d, mm	p, mm	D_1, mm	D, mm	$\overline{D}=D/d$
10	0.75	3.2	7.8 ± 1	31.6 ± 3	42
7.2	0,83	3.1	13.5 ± 4	34.5 ± 2	41.5
5	0,9	2.6	22 ± 1.5	27 ± 2	30
4.46 3.05	Iron on glass [2]				4.8 4.8
8.34 6.42	Iron on quartz [2]				8.2 7.5
9,57 7.79	Aluminum on glass [2]				5.73 3.6
10.1 7,0	Polystyrene on glass [2]				3.75 3.4

(within the lighter part at the center in the photograph), and it may be that this even tends to become smaller as the speed increases (Table 1). High-speed cinephotography (SFR-L camera) showed that the network of cracks arises immediately after the passage of the shock wave, and then the material shatters and is ejected, which is accompanied by loss of transparency in the collision zone. The angle of the cone of damaged material (in section) is about 140-150°, which is close to the values given in [6]. These results also agree qualitatively, regarding the nature of the damage, with those of [2]. Table 1 gives the mean values for D and D_1 (from 4-6 experiments), and also for the depth p of the crater in glass. It also gives (selectively) the data [2] of results for particles of polystyrene from an electrostatic accelerator ($\rho = 1.04$ g/cm^3), and also for aluminum and iron particles, in each case striking glass (crown glass, $\rho_1 = 2.3$ g/cm^3) or quartz ($\rho_1 = 2.2$ g/cm^3). The dimensions of the damage zone do not vary in step with the particle size. In [2], the particle size was less by a factor $5 \cdot 10^2$-10^3 than the values used here; the dimensionless size $\overline{D} = D/d$ was reduced by a factor of 4-6 (Table 1). Within the error of experiment, results for particles with d = 0.1-0.3 mm agree with those for particles about 1 mm in size. Therefore, if there is a scale factor, it becomes appreciable only for $d < 0.1$ mm.

In all the experiments with large particles ($d \sim 1$ mm), the diameters were less by 2-2.5 orders of magnitude than the diameter of the specimen, which means that the finite size could have no effect on the surface damage. This agrees with the results from cinephotography.

There are two possible reasons for the discrepancies between the results of [2] and the present results:

a) the scale factor becomes effective for 10^{-3} mm $\leq d < 0.1$; however, glasses are not known to contain any structure with such a characteristic dimension, and the more so, since the lower bound to this range is close to the wavelength of visible light (in both groups of experiments we used optical glass, which presupposes homogeneity in that range);

b) the difference in mechanical properties between the materials of [2] and those used here (although optical crown glass was used in both instances). This obvious assumption conflicts with our results on quartz and

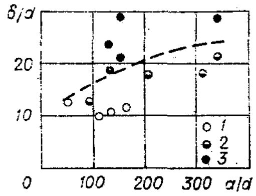

Fig. 2

ordinary glass, where the scale of the damage in each case is much the same, and is close to that for the main material, namely, K-8 glass, although the mechanical properties are certainly different.

A decision might be obtained by performing experiments over the entire size range with a single material.

If v is about 10 km/sec, the thickness of a metal obstacle hazardous from the viewpoint of penetration is in the range 5-10d [7]; in the case of glass or quartz, ejection from the rear side of the disk becomes appreciable for $\delta \sim$ 20-25d, while breakthrough occurs for $\delta \gtrsim$ 10d. These results were obtained with particles having d ~1 mm colliding with disks having δ = 8, 15, and 20 mm.

The shock wave arising from the point of impact goes over rapidly to an elastic compression wave (transverse waves are present as well by virtue of the free surface). A tension wave is reflected when the initial wave reaches the free side surface, and fragments may then become detached from the side (edge failure, Fig. 1). The tensile stresses become cumulative as the waves converge into the specimen, and at some point they give rise to a network of cracks, which may penetrate through the entire thickness of the material. The physical model indicates that the size of the zone of secondary damage increases with the particle speed for d constant; this zone always lies on the diameter passing through the point of collision, but on the other side of the center of the disk. If the distance from the point of collision to the center is reduced, the distance from the center to the zone of secondary damage is also reduced, and in the limit the two zones coincide.

All these features of the brittle failure are clear in the specimen shown in Fig. 1; cinephotography indicated that the cracks due to secondary failure correspond to elastic waves of speed 4.7-5.2 km/sec, which is in agreement with the characteristics of the material. When the specimen is broken, this zone of secondary damage is one of the centers at which the fracturing occurs. Damage due to tension-wave cumulation in dynamic loading has long been known [8].

If the specimen is mounted rigidly in a holder of material having an acoustic impedance greater than that of glass, one gets cumulation of the compression waves; in that case there is also secondary damage. In those experiments, the specimen was mounted in a massive steel holder that had been preheated slightly.

The danger of brittle failure increases on collision at an angle; the maximal damage occurred for α of about 30-45° to the normal in our experiments.

Therefore, the damage to glass specimens (windows etc.) is a rather complex process governed by various factors; in the range accessible to experiment, one can perform an engineering evaluation of the final result. Figure 2 shows a diagram of the type of failure for v = 7.2-7.4 km/sec in relation to the ratio of the thickness δ and diameter a to the particle size (1 represents complete failure; 2, failure in the form of radial through cracks; and 3, only secondary damage). The final damage is only slightly dependent on the position of the point of collision. The region above the broken line is that in which the specimen is not completely disrupted.

As regards surface meteoritic erosion of optical materials, it must be borne in mind that the area of the damage will exceed the area of the cross section of the particle by factors ranging from $0.3 \cdot 10^2$ (a lower bound estimated from [2] for light and heavy particles) up to 10^3 (an upper bound derived from the present study for heavy iron particles). These results were obtained for the lower end of the range of meteoritic velocities.

The purpose of this study was to give a phenomenological description of the failure in brittle materials in high-speed impact, and it was not intended to compare the results with theoretical models such as that of [9].

The author is indebted to G. V. Pryakhin for assistance in the experiments, and also to N. N. Protasov and T. N. Nazarova for discussion of the results.

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ACTION OF AN EXPLOSIVE PLASTIC WAVE ON A PLATE

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UDC 531.391.539.371

The action of a transient loading on an infinitely elastic plate, freely covering the surface of an ideal compressible liquid, was discussed in [1-3]. A review of work on the dynamics of a plate under the action of a transient loading is given in [4].

The motion of a rectangular plate of finite dimensions is considered, under the action of a plastic, plane, explosive compression shock wave, incident at an angle. The plate is the side of a rectangular cavity filled with an ideal compressible liquid. The cavity is in a dense medium (earth) and is bounded by rigid immovable walls. In this same medium, at a distance of $\eta_0 a$ and at an angle α to the surface of the plate, a plane layer of an explosive charge with thickness $2a$ is detonated (Fig. 1), where $\eta_0 = (z \cos \alpha)/a$ is the dimensionless distance. The explosive charge, when detonated, is converted instantaneously into gas at high pressure without change of volume, as a result of which an initial pressure p_2 is applied to the surface of the medium AB, which causes the formation in the medium of a plastic compression shock wave. The velocity of the front and the parameters of motion of the medium are known (determined by a computational or experimental method [5, 6]).

It will be assumed that the diagram of compression of the medium is described by a power law and has an asymptote, corresponding to the pressure, which tends to infinity. Then the pressure at the front of the wave is determined by the formula [5]

$$p_1 = C_1(\eta_0 + \eta_1)^{\lambda},$$

where $C_1 = p_2 \beta A_0^{m+2}$; $\lambda = \omega(m + 2)$; η_1 is a dimensionless distance, measured in the direction normal to the front; the quantities β, A_0, m, and ω depend on the exponent of compression of the medium n and the isentropy exponent for the detonation products and are found by well-known relations [5].

Using the results of [7, 8], we write the expression for the pressure of the shock plastic wave at the surface at the instant of reflection in the form

$$p = p_1(1 + q) \cos \alpha,$$

Ufa. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 4, pp. 131-136, July-August, 1976. Original article submitted July 4, 1975.