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EFFECT OF SPECIMEN TEMPERATURE ON THE BREAKING POINT FOR SPLITTING-OFF IN AMG-6 ALUMINUM ALLOY

Yu. V. Bat'kov, S. A. Novikov,
V. A. Sinitsyn, Yu. S. Sobolev,
and A. V. Chernov

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The investigation of the temperature dependence of the strength of constructional materials under intense shock loads, including breaking loads, is of considerable practical interest. There are certain technical difficulties involved in loading the materials and making the required measurements in such experiments. Hence, the number of papers devoted to this problem is extremely limited. In [1, 2] data is given on the elastic–plastic properties of a number of metals at normal and high temperatures, obtained by investigating the parameters of elastic waves excited by an explosion. In [3, 4] investigations were carried out of the temperature dependence of the breaking point for splitting-off in steel and copper. In the present paper we investigate the effect of the specimen temperature on the breaking point for splitting off in widely used AMG-6 aluminum alloy in the temperature range from 0°C to 550°C, i.e., practically up to the temperature at which the alloy begins to melt.*

The specimens investigated were cut from a single blank and were disks 70 mm in diameter and 10 mm thick with a conical side surface (at an angle of 45°).

The specimens were tested on special equipment, a diagram of which is shown in Fig. 1.

Specimen 1 was heated by the radiant heat flux from a Nichrome filament heater 2 with a power of 3 kW (50 A, 60V), mounted on a heat-resistant screen. The temperature of the specimen was monitored with a thermocouple 3 up to the instant when the specimen was loaded. The time taken to heat the specimen up to a temperature of 550°C was ~20 min. The nonuniformity of the temperature over the specimen thickness at the instant of loading did not exceed ~5°C. The heated specimen was displaced by means of a cable 4 along the direction 5 on a special platform 6 under the loading device 7. The specimen was loaded by a shock aluminum plate (110 × 150 × 4 mm), scattered up to the required velocity by a glancing detonation wave from a layer of explosive placed on it, initiated simultaneously along one of the faces of the plate from the explosive. To prevent splitting-off in the striker the latter was separated from the explosive by a layer of porous material. The velocity of the striker was varied by varying the thickness of the layer of explosive, and simultaneity of the shock on the surface of the specimen was achieved by placing the striker at a certain angle to the specimen depending on the velocity of the striker. The split-off plates formed as a result of the loading were collected in practically undamaged form using a porous damper 8 of low rigidity placed in a steel container 9.

The method of determining the breaking point was as follows. A shock load was applied to the specimen and the presence or absence of split-off was observed visually after the experiment. (If necessary the specimen was cut along an axis, a thin section was made, and metallographic analysis was carried out.) By a gradual

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*The melting of alloys and solid solutions is characterized by a melting temperature range. For AMG-6 alloy the temperature at which melting begins is ~570°, and the temperature at which melting ends is ~640°C [5].

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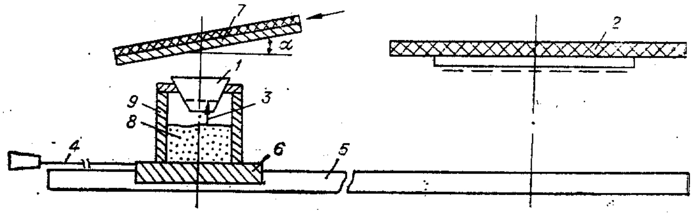

Fig. 1

TABLE 1

No.	Velocity of striker, m/sec	Temp. of specimen, T, °C	Splitoff breaking strength, σ_s, kbar	Notes
1	400	0	30	Beginning of breakage
2	400	—13	30	•
3	360	15	27	No split-off
4	320	200	24	Beginning of breakage
5	310	200	23	•
6	270	350	20	•
7	265	400	19.5	Split-off
8	250	400	18	Beginning of breakage
9	200	410	14.5	No split-off
10	190	450	14	Beginning of breakage
11	200	450	14.5	•
12	140	500	10	•
13	130	500	9	No split-off
14	120	500	8	•
15	90	550	6.5	Beginning of breakage
16	80	550	6	•
17	75	550	5.5	No split-off

change in the velocity of the striker plate the loading conditions for which split-off began was found. We took as the value of the breaking point for split-off σ_S the value of the tensile stress in the plane in which a crack was formed, obtained theoretically (for the known equations of state of the material of the specimen and the striker), or using the pressure in the compression wave in the specimen measured in the experiment. The accuracy of σ_S obtained in this way is governed by the value of the step in the pressure change, which in this experiment was ~ 2 kbar, and the accuracy of the equation of state employed. Since the value of the breaking point in AMG-6 alloy is small, one of the possible approaches to determining it theoretically is to use the acoustic theory of split-off. It is well known that when a compression pulse is reflected from a free surface, a pulse will propagate in the material of the same form as the original pulse, but of opposite sign. Consequently, in the acoustic approximation the value of σ_S will be equal to the maximum value of the pressure in the compression wave propagating into the specimen in the experiment in which split-off is bound to begin. In calculations in the low-pressure range (up to 10 kbar) the velocity of the shock wave was taken to be equal to the velocity of the longitudinal elastic wave in an unbounded medium (6.3 km/sec), and for the range above 10 kbar we used the equation of state of the material of the striker and the specimen in the form of a linear relation between the wave velocity D and the mass velocity u [6]:

$$D = 5.25 + 1.39u.$$

The effect of the temperature (preliminary heating) on the form of the equation of state was ignored. In a number of experiments we measured the pressure in the specimen using a manganin probe and the apparatus described in [7]. The thickness of the probe together with the insulating plastic films was 0.12-0.16 mm, the initial resistance was 35 Ω, and the area occupied by the sensitive element was 5 × 6 mm. The measurements were made in a bridge circuit. The current in the probe during the measurements was 4.5 A. The error in measuring the amplitude of the pulse pressure did not exceed ± 10%.

The results of the investigation are presented in Table 1. The amplitudes of the compression waves obtained by calculation and by experimental measurements agree with one another to within 10%. The characteristic time τ during which the tensile stresses act, determined by the length of the pressure pulse measured in the experiment, is $1.3 \cdot 10^{-6}$ sec. The conditions under which the tests were made corresponded to a deformation velocity of $\sim 10^5$/sec.

Figure 2 shows the temperature dependence of the breaking point for split-off, constructed from the data in Table 1. The value of σ_S at 550°C (in the region where melting begins) is 5 times less than at normal temperature, but is nevertheless a quite high value of ~ 6 kbar. The curve obtained has a pronounced upward

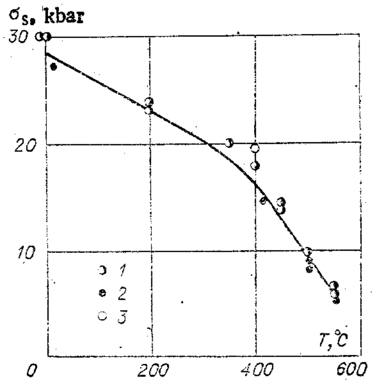

Fig. 2

convexity. The relatively weak reduction in σ_S as the temperature increases on the initial part of the $\sigma_S = f(T)$ curve, pointed out previously for steel [3] and for copper [4], should be noted.

The duration of the tensile action τ and the value of the breaking point obtained experimentally enable us to compare the experimental results with the data obtained from the kinetic theory of the strength of solids [8], according to which the breaking point σ, the life τ (the time from the instant when the load is applied to the instant when breaking occurs) and the temperature T are related by the equation

$$\tau = \tau_0 \exp\left(\frac{U_0 - \gamma\sigma}{kT}\right), \qquad (1)$$

where k is Boltzmann's constant, τ_0 is the period of atomic oscillations, and U_0 and γ are constants of the materials. Substituting into this equation the constants for aluminum [9] $U_0 = 52$ kcal/mole, and $\gamma \cong 2$ kcal · mm^2/mole · kg, and the value of σ_S obtained in the experiments with different values of the specimen temperature, we obtain that the characteristic breaking time should be many orders of magnitude less than the time of action of the tensile stress in the experiment.

In [9] considerable disagreement was found between the experimental data and the results obtained using Eq. (1) of S. N. Zhurkov in the range of stress-action times on the order of 10^{-6} sec and normal specimen temperatures for values of the constants τ_0, U_0, and γ found for large values of τ (10^{-3}-10^{-7} sec).

In [10] the nonapplicability of the kinetic theory of the strength of materials to describe split-off is due to the fact that in this case the length of the tensile pulse is comparable with the dimensions of the specimens and destruction occurs due to the store of elastic energy. We take as the split-off criterion the equality between the store of elastic tensile energy and the work done in rupturing the material λ:

$$\lambda = \int_0^\tau \frac{c\sigma^2 dt}{AE},$$

where τ is the length of the rarefaction wave; σ, stress; c, velocity of sound; E, modulus of longitudinal elasticity; $A = 2(1-\mu)\,[(1+\mu)(1-2\mu)]^{-1}$; and μ, Poisson's ratio. Since in the acoustic approximation the amplitudes and durations of the rarefaction wave and the compression wave are equal, using the values of τ and σ measured in these experiments (the record of the pressure pulse obtained with the Manganin pickup), we can estimate the energy required to rupture the AMG-6 alloy at normal and high temperatures. At normal temperatures $\lambda_n \approx 4.3 \cdot 10^5$ J/m^2, and at 500°C, $\lambda_T \approx 0.7 \cdot 10^5$ J/m^2, i.e., the energy required to rupture the alloy at T ≈ 500°C is 6 times less than that required at normal temperature.

The extension of the investigations of split-off at increased temperatures, when the dependence of the breaking point on time is most pronounced, is of independent interest in refining the functional dependence of the main parameters of the destruction of the material (σ, τ, and T) in the insufficiently studied region of microsecond loading-pulse lengths.

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INTERACTION OF A SURFACE WAVE WITH A CRACK IN A CONCAVE HALF SPACE

I. S. Guz' and V. N. Katanchik

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The interaction of a Rayleigh wave with a stationary crack in a rectilinear surface was treated in [1, 2]. It was shown that under certain conditions a surface wave can generate dynamic stresses large enough to extend a crack. However, there have been no studies of the interaction of a surface wave with a crack in a curvilinear half space, although this case is encountered more frequently in practice. We use the method of dynamic photoelasticity to observe the interaction of a surface wave with an edge crack along and normal to a concave half space. The research was performed on 350 × 400 × 15-mm samples of polymethyl methacrylate. A surface wave of duration up to 50 μsec was excited by a point microexplosion on the linear portion of the sample joined with the curvilinear part. The interaction of the surface wave with a crack was recorded in circularly polarized light by an SFR-1 high-speed motion-picture camera at $1.5 \cdot 10^6$ frames/sec.

We first considered the propagation of a surface wave along a concave half space without a crack, and then its interaction with a crack. The film strips in Fig. 1 illustrate the propagation of a surface wave along a concave half space of constant radius of curvature R = 50 mm. They show that in the propagation of a Rayleigh wave along a rectilinear half space the stress distribution in the wave has a complex shape: There are three stress rosettes, two of which are located directly on the surface of the half space in front of and behind the main disturbance. When a wave moves in a curvilinear half space there is a continuous redistribution of elastic energy in the surface wave. In the $0 < \alpha < 90°$ part, where α is the central angle, there is first observed the development and strengthening of the surface rosette in front of the main disturbance as a result of a partial weakening of the last and second surface rosettes, and then the transformation of the main disturbance into a body wave traveling with the velocity of a transverse wave. It should be noted that independently of the radius of curvature (R = 10, 25, 50, and 75 mm) the transformation of the surface wave into a transverse wave occurs at $\alpha = 90°$. The strain measurement of dynamic stresses in the rectilinear portion of the half space produced by a surface wave shows approximately identical duration of the compression and tension phases in the Rayleigh pulse (Fig. 2a), i.e., $T_c = T_t = 0.5T$, and the amplitudes of the compressive and tensile stress components are in the ratio 1 : 1.5. Figure 2b-e shows oscillograms of the surface stresses and the corresponding film strips of the distribution of maximum tangential stresses in the wave in passing through the $\alpha = 45$, 90,

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