# DEVELOPMENT OF PERTURBATIONS AT AN ALUMINUM–COPPER CONTACT BOUNDARY IN A NONSTEADY REGIME OF OBLIQUE COLLISION

O. B. Drennov

UDC 534.222.2

Physical processes involved in oblique collisions are usually described for the steady-state phase of motion of the plate acting as the projectile. In this case, the flight velocity w depends only on the ratio of the mass of explosive to the mass of the plate ($R = m_1/m_2$) and the propellant capacity of the explosive. The latter quantity is accounted for in semiempirical formulas through the detonation rate.

It is usually assumed that the projectile is rotated to a constant value of the angle $\gamma$ over the flight distance $d_*$, which is determined by the thicknesses of the layer of explosive in the plate [1]. At $d < d_*$, two plates will collide at an angle different from the theoretical angle [1, 2]. This in turn leads to a change in the loading regime and the parameters of the wave disturbances in the contact zone. The authors of [3] made a study of the geometric form of the contact boundary between layers of metals after high-speed oblique collision with a successive reduction in the initial distance between them. A substantial reduction (by a factor of 5-7) in the parameters of the perturbations was seen with a change in the flight distance for the projectile from d = 15 to d = 1 mm for copper–copper, steel–copper, and aluminum–copper pairs.

In this work, we studied the development of perturbations at an aluminum–copper contact boundry for oblique collisions at the initial phase in the motion of the projectile plate.

Figure 1 shows a diagram of the setup of the tests. A stationary plate 2 of M1 copper measuring 100 × 60 × 5 mm was placed on a massive steel base 1. The projectile plate, made of aluminum alloy AMG and measuring 100 × 60 × 5 mm, was positioned above the copper plate with the gap d. A striker made of aluminum alloy AMG and measuring 150 × 120 × 4 mm was placed above the two-plate packet. The minimum distance between the striker and the projectile plate h = 20 mm, which ensured that the collision parameters would be steady [1]. A layer 5 of trotyl explosive was placed on the surface of the striker, and a sliding plate detonation wave was excited in the layer. To prevent the occurrence of cleavage effects in the striker material, a thin interlayer 6 of material with a low acoustic impedance was positioned between the striker and the explosive. Its presence did not affect the rate or symmetry of motion of the striker [4]. From one test to the next, we changed the distance d between the surfaces of the stationary and impacting plates.

Under the loading conditions that were realized $v_c > c_{Al} > c_{Cu}$ (the velocity of the point of contact being greater than the speed of sound), the initial angle of bending of the impacting plate $\psi$ remains equal to the angle of shock-wave rotation during the time of circulation

TABLE 1

| Number of test | $v_c$, mm/µsec | d, mm | a, µm | λ, µm | Number of figure (magnification) |
|---|---|---|---|---|---|
| 1 | 5,5 | 0,1 | 20±5 | 85±15 | 2<br>(×100) |
| 2 | 5,5 | 0 | 45±5 | 90±15 | 3<br>(×100) |
| 3 | 6 | 0,1 | 15±5 | 60±15 | 4<br>(×100) |
| 4 | 6 | 0 | 40±5 | 70±15 | 5<br>(×100) |
| 5 | 6,9 | 0 | 20±5 | 55±10 | 6<br>(×200) |

---

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 41-44, May-June, 1989. Original article submitted January 25, 1988.

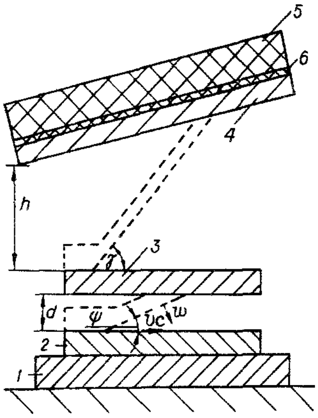

Fig. 1

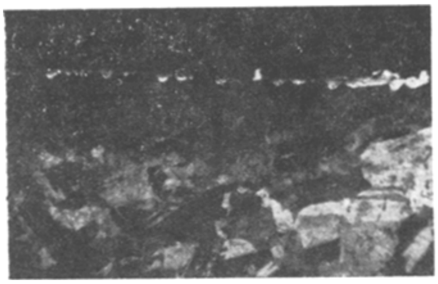

Fig. 2

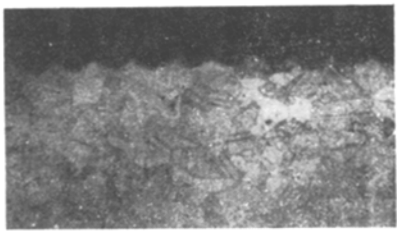

Fig. 3

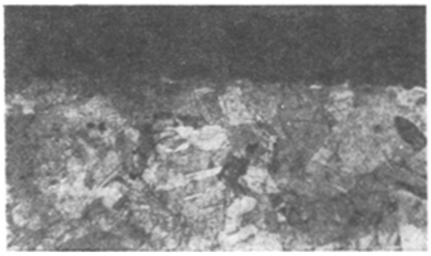

Fig. 4

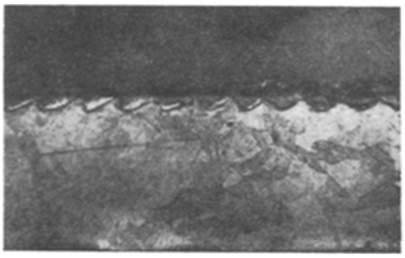

Fig. 5

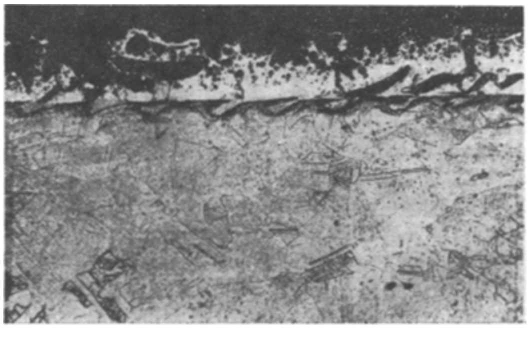

Fig. 6

of the wave about the plate. As a first approximation, this angle can be taken equal to $2\delta/c_{Al}$ ($\delta$ is the thickness of the impacting plate). Knowing the flight velocity of the plate, we obtain the value of the distance over which a constant initial angle of rotation is maintained: $d' \approx w2\delta/c_{Al}$. For the conditions realized in the experiments, $d' \approx 2$ mm. We used the specimens tested under dynamic loading conditions and prepared sections for metallographic analysis of the condition of the aluminum–copper contact boundary. The main results of the experiments are shown in Table 1, where $v_c$ is the velocity of the contact point, d is the flight distance of the impacting plate, and $a$ and $\lambda$ are the amplitude and length of the perturbation wave realized at the contact boundary (the mean values after counting 20 successive perturbations). Photographs of the microsections of the contact boundaries are shown in Figs. 2-6.

We first performed two series of identical experiments in which the contact surfaces of the loaded plates were finished to roughness class Rz 20 (surface roughness no greater than 20 μm) and class Rz 0.05 (surface polished to mirror finish). We did not determine the difference in the parameters or the geometric form of the perturbations that were realized.

Of most interest are the tests involving oblique impact of the plates at d = 0 and 0.1 mm. Analysis of the experimental data shows that when the plates are placed next to each other (without a gap), the amplitude of the disturbances is roughly twice as great as for the variant with the gap d = 0.1 mm, i.e., at $d \to 0$ the amplitude of the perturbations does not vanish but decreases succesively from $a$ = 50-60 μm at d = 1 mm to $a$ = 15-20 μm at d = 0.1 mm. It then increases to $a$ = 40-45 μm at d = 0.

The formation of a jet is not possible for the given test conditions in the loading regime with d = 0 (tests 2, 4, and 5). There are no initial gaps whose closure is accompanied by the formation of a detonation jet. The perturbations on the contact boundary are the result of development of Kelvin—Helmholz instability. The oblique shock wave causes rotation and relative slip of the layers of metal along the contact boundary behind the shock front. Narrow boundary layers of the metal fuse and there is a significant loss of strength and a transition to the quasiliquid state. The relative flow of the layers is accompanied by realization of a tangential discontinuity of velocity $\Delta u$ and the development of shear instability. It follows from the conservation laws on the front of an oblique shock wave [5] relative to the loading conditions realized in tests 2, 4, and 5 that the tangential velocity discontinuity $\Delta u \geq 1$ mm/μsec in the relative flow of aluminum and copper.

At d = 0.1 mm (tests 1 and 3), the material at the point of contact of the loaded plates is subjected to intensive plastic shear strains. This material undergoes partial fusion and becomes liquid in thin boundary layers. A micro-detonation jet which fills the 0.1 mm wide gap is formed. Relative flow of three different flows also takes place: from the material of the impacting plate, from the material of the stationary plate, and in the detonation jet. In other words, two parallel tangential discontinuities are realized. However, they partially stabilize one another relative to perturbations with wavelengths that are long compared to the distance between discontinuities [6]. Thus, the amplitude of the perturbations decreases.

Consequently, the micro-detonation jet formed in narrow gaps performs the opposite function: instead of generating disturbances at the contact boundary, it partially stabilizes perturbations already created.

## LITERATURE CITED

1. A. A. Deribas, Physics of Explosive Strengthening and Welding [in Russian], Nauka, Novosibirsk (1980).
2. A. V. Krupin, V. Ya. Solov'ev, N. I. Sheftel', et al., Deformation of Metals by Explosion [in Russian], Metallurgiya, Moscow (1975).
3. G. E. Kuz'min, V. A. Simonov, and I. V. Yakovlev, "Dependence of the wave parameters in explosive welding on the phase of acceleration of the impacting plate," Fiz. Goreniya Vzryva, No. 3 (1976).
4. B. L. Glushak, S. A. Novikov, et al., "Study of the ignition of TNT and TG50/50 by short-lived shock waves," Fiz. Goreniya Vzryva, No. 6 (1981).
5. R. Courant and K. O. Freidrichs, Supersonic Flow and Shock Waves, Springer-Verlag (1977).
6. N. G. Kikina, "Effect of viscosity on the stability of tangential discontinuities in an incompressible medium," Akust. Zh., 13, No. 2 (1967).