The Influence of Projectile Geometry on Adiabatic Shear and Target Failure

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An examination has been carried out of the ability of projectiles of three different geometries to perforate plates of an age hardened aluminum alloy. It was found that flat-ended projectiles perforate the target with greater ease than projectiles with more rounded ends. The results are discussed in terms of the ability of a particular projectile geometry to promote adiabatic shear during penetration and the mode of fracture when projectile breakout occurs.

Adiabatic shear is the degree to which adiabatic shear occurs in which adiabatic heating occurs can reduce the energy required for penetration. It is known, in a general form, that materials susceptible to adiabatic shear have a significant influence in determining whether a material will be susceptible to adiabatic shear. Some materials (such as titanium and aluminum alloy type 2014) are prone to adiabatic shear whereas it has not been detected in others (such as type 1200 aluminum).

Another important parameter is the shape of the impacting projectile since this is known to affect the energy for target perforation. For materials not susceptible to adiabatic shear this is due to the projectile shape affecting the deformation pattern and the extent of the petal tube. For materials susceptible to adiabatic shear the degree to which adiabatic shear occurs can also be influenced by the deformation pattern associated with the penetrating projectile. If the deformation is sufficiently concentrated, rises in temperature due to heat generation from plastic deformation can cause thermal softening and so promote adiabatic shear which can lead to catastrophic failure.

The purpose of this investigation was to determine the influence of projectile geometry on the formation of adiabatic shear bands and how such shear bands affect the penetration characteristics of the material.

EXPERIMENTAL

1.1) Target Material

The target material used was 10 mm thick type 2014 aluminum alloy in the T6 condition, a material which shows a strong tendency to form adiabatic shear bands when penetrated by projectiles.

1.2) Penetration Experiments

The projectiles were in the form of hardened steel rods 7 mm diam and 70 mm long. The steel used was type 4340. Three projectile geometries were used; flat ended, hemispherical ended, and ogival. To obviate the frictional drag between the rod and the walls of the hole after perforation, the shanks of the projectiles were reduced to 6 mm diam, for a distance of 2.5 cm commencing from a point approximately one projectile diameter from the front end. The projectiles were fired from a commercial stud gun, the velocity being varied between 80 m/s and 240 m/s by using different amounts of propellant.

Projectiles were fired at various velocities into target plates to determine the minimum velocity at which penetration would occur ($V_p$). This was carried out using the equipment described in Ref. 6 so that force penetration behavior could be measured. Hence both the resistance that the plate offered to penetration and the minimum velocity for penetration could be measured.

To examine the progress of the deformation during penetration, it is necessary to stop the penetration at various stages but to keep other parameters, most importantly the velocity of penetration, constant. To do this, a "stepped" projectile was used and its principle is outlined in Fig. 1. The "head" of the projectile was made such that it could be adjusted to a desired depth of penetration ($\Delta P$); when the projectile had reached this depth the wider section sheared out a large plug of material that contained the deformation pattern due to the head. These plugs were sectioned and examined metallographically.

1.3) Metallography of Penetrated Plates

The plates were sectioned and examined metallographically to examine the deformation and failure caused by the different projectile geometries. The plate material showed marked banding characteristics due to alloy segregating so that it was sectioned as nearly as possible parallel to the rolling direction thus making it easier to examine the flow pattern produced by the penetrating projectile.

To determine the type of fracture produced by projectile breakout, chromium-shadowed two stage carbon replicas were made of the fracture surfaces and these were examined in an electron microscope.

RESULTS

2.1) Perforation

Perforation of the 10 mm thick target plates occurred at projectile velocities above 135 m/s for the flat-ended projectile. 180 m/s for the hemispherical projectile and 240 m/s for the ogival projectile. The highest velocity obtainable with the present equipment
Fig. 1—The principle of the stepped projectile. (a) A collimated projectile is fired at the target material. (b) The head of the stepped projectile penetrates the desired depth (ΔP). This can be varied between zero and full plate penetration. (c) When the head has penetrated ΔP a large plug of material containing the deformation due to the band is sheared out by the larger diameter projectile.

is 240 m/s and so the behavior associated with ogive projectiles above their minimum perforation velocity could not be examined.

At 135 m/s the flat-ended projectile caused a plug to be ejected but the projectile became stuck in the plate due to frictional drag; 135 m/s was thus taken as the critical velocity.

The variations of force with penetration of target for projectiles fired at several different velocities are shown in Figs. 2, 3, and 4.

The flat-ended projectile penetrated with a continued decrease in the maximum force as the velocity was increased above the minimum for perforation.

(Vc = 135 m/s). The maximum force occurred at a depth near 3.5 mm for each velocity and the force decreased as the projectile penetrated to greater depths, finally leading to breakout.

The hemispherically-ended projectile showed a similar decrease in force to perforate with increased velocity; however Vc was higher (180 m/s) and the penetration for peak force (8 mm) was greater than for the flat-ended projectile. In both cases the maximum force at Vc was of the order of 50 KN.

Although the results for the ogive projectile are restricted by the velocity range available, they did show that the maximum force increased with increasing ve-