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THE EFFECT OF STRIKING VELOCITY ON PERFORATION ENERGY FOR MILD STEEL PLATES

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INTRODUCTION

The energy required to fracture metals in a ductile mode at high strain rates is determined by the balance between two opposing effects. On the one hand, there is the effect of increasing strain rate in raising the initial yield stress of the material; on the other, there are thermal effects, as the process approaches adiabaticity, which lower the flow stress in the plastic range.

The first of these effects, the raising of the initial yield stress, is a very complex effect involving many possible mechanisms [1]. It can be observed at low strain rates but it only becomes an order-of-magnitude effect at very high strain rates where the deformation velocity approaches the "critical velocity" for the material.

The thermal effects, however, may become significant at much lower deformation velocities, depending on the geometry of the deformation process and the extent to which the deformation is concentrated into shear bands.

The possibility therefore arises that, as one increases the velocity of deformation, the energy required to perform a particular manufacturing operation might first decrease due to thermal effects but then increase at higher velocities as the elastic energy necessary for initial yield increases. In other words, there could be a minimum in the energy versus deformation velocity curve; where there is such a minimum, high speed forming processes might aim to take advantage of it.

Minima have been tentatively reported by the present authors [2] for the penetration of steel plates by pointed projectiles and by Austin et al [3] for the cold forward extrusion of steel. Unfortunately, the field is experimentally difficult and there is need for further confirmatory work, particularly at velocities above the minimum energy point. The present paper is a contribution in this direction.

The problem of penetration of a plate by a pointed indenter or projectile occurs in many fields of engineering, e.g., in hardness testing, weaponry and explosive-powered fastening processes. Both weaponry and fastening are essentially fracture processes and it is these with which we shall be concerned here. The only other qualification is that all fractures will be ductile, in what is called a "petalling" mode, as opposed to spalling or plugging [4].

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EXPERIMENTAL RESULTS AND DISCUSSION

All experimental results reported here were obtained on industrial fastening guns, in some cases modified to allow much higher energy input than normal. In all cases, the target material was bright mild steel strip, 6.3 mm thick, hardness R_B84 (approximately 167 V.D.H.). Incident velocities were measured with a magnetic device invented by Baldwin [5]; exit velocities were measured by using perforation of spaced aluminum foils to trigger a timer.

Two series of tests are reported. The first used cylindrical projectiles, 4.75 mm diameter, with a 30° conical point; most were 25 mm long but some 75 mm long were used to extend the curve to lower velocities. The results are shown in Figure 1, which plots the energy, E, absorbed during penetration, against the striking velocity, V. If M is the mass of the projectile and V_r, the residual or exit velocity, E is calculated from:

$$E = \frac{1}{2} M (V^2 - V_r^2) . \tag{1}$$

All points in Figure 1 are at or above the "ballistic limit", V_{50}, the velocity which has an even (50 - 50) chance of producing perforation of the plate for the particular geometry in use.

The results have been replotted on a logarithmic velocity scale in Figure 2, which also reproduces some of the results of reference [2]. They cover a range of velocities above that used in reference [2] but they lie well below the latter because the targets were softer. (R_B 84 as against R_B 92).

It is evident that the energy absorbed in perforation increases with striking velocity, which is in line with most of the data presented by Ipson and Recht [6] for cylindrical and chisel-nose projectiles. Ipson and Recht reported their results in terms of a hypothetical "minimum perforation velocity", V_x, defined by the equation

$$V_r = \frac{M}{M+m} (V^2 - V_x^2)^{1/2} \tag{2}$$

where m is the mass of material driven from the target. In our case, m is zero, so our energy, E, is simply

$$E = \frac{1}{2} M V_x^2. \tag{3}$$

Attempts to extend the curve to even higher velocities using high powered rifles failed because of instability of the projectiles.

The second series of tests reported in Figure 2 covers a range of velocities below the ballistic limit. These velocities are experimentally more difficult to investigate. They were covered here by using a projectile with an ogival point at one end and a threaded length at the other, so that a heavy inertial mass could be either screwed to the rear end of the projectile or used as a piston behind the projectile. It was necessary to determine the powder load which would produce complete penetration with different inertial masses and then determine the velocity which this particular powder load produced in the assembly of projectile plus piston.

There are possible sources of error in this procedure but the results are reported as the best available in an experimentally difficult regime. They support the previous conclusion that the energy for penetration does

increase with increasing striking velocity over the velocity range, 50 m/s to 300 m/s. The particular ogive used was not very different to a 30° cone and it has been shown [2, 7] that there was no significant effect of the difference in profile, on the penetration energy.

CONCLUSION

It can be concluded from this work that the energy to fracture, by penetration or perforation in a fully ductile mode, of a mild steel plate at high velocity, increases with the striking velocity. This confirms the tentative suggestion made in previous work that for certain geometries, there is a minimum in the energy versus velocity curve for a penetration or ductile perforation process.

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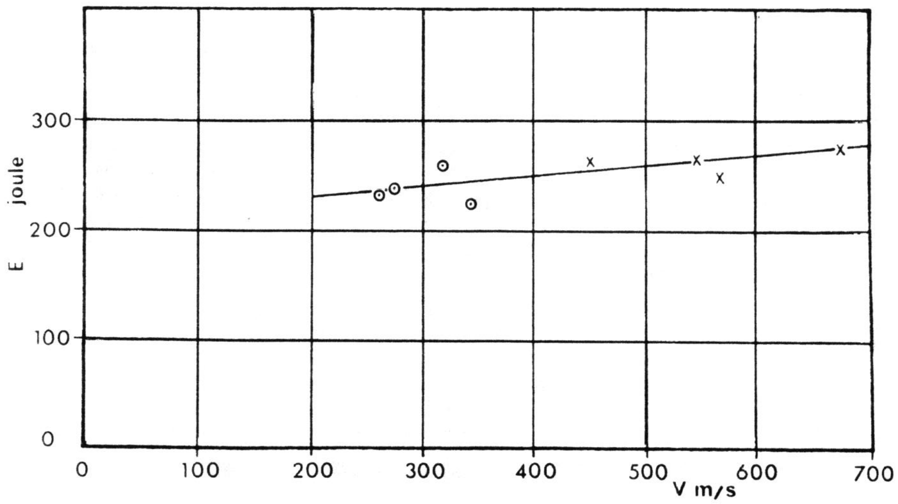

Figure 1 Perforation Energy Versus Striking Velocity for Velocities Above the Ballistic Limit. Target: Mild Steel (R_B 84). Projectile Point: 30° Cone

x projectile mass 3.6 g.
o projectile mass 7.5 g.

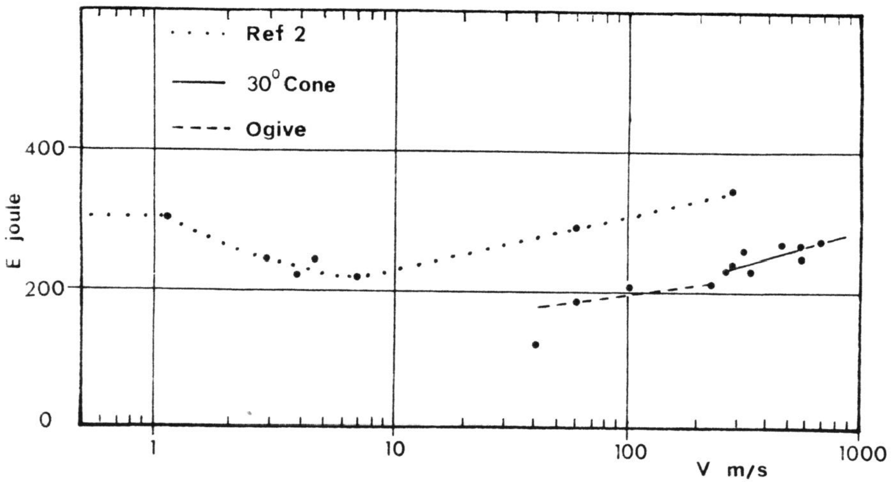

Figure 2 Comparison of Present Results with Those of Reference 2, in Which the Target Hardness was R_B 92