SOME METALLURGICAL ASPECTS OF SHAPED CHARGE LINERS

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Abstract. This paper reviews the traditional selection criteria for shaped charge liners, and demonstrates some confusions that arise. When considering possible new liner materials it is proposed that measurement of dynamic mechanical properties, rather than the usual more readily available static data, would be helpful, particularly to mathematical modellers.

INTRODUCTION

The Shaped Charge Jet

The first section of this paper reviews what is expected from a conical shaped charge liner. As illustrated in Figure 1, the shaped charge jet tip reaches 10 kms^{-1} some 40 µs after detonation, giving a cone tip acceleration of about 25 million ***g***.

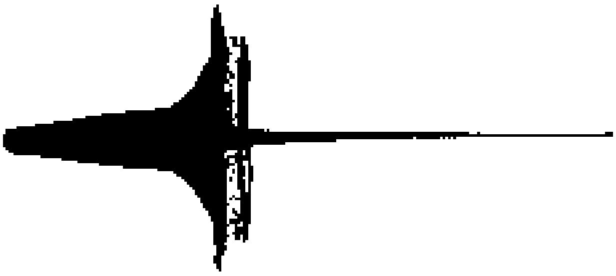

Figure 1. Flash X-ray of a collapsing copper cone.

At this acceleration the tip would reach the speed of light, were this possible, in around 1.5 seconds. But of course, it reaches a terminal velocity after only 40 millionths of a second. It is difficult to think of any other terrestrial event as fast as a shaped charge jet tip. The jet tail has a velocity of 2-5 kms^{-1} and so, as illustrated in Figure 2, the jet stretches out to a length of about 8 cone diameters (CDs) before particulation occurs.

Figure 2. Flash X-ray of a copper jet penetrating an aluminium alloy target.

The stretching occurs at a high strain rate, requiring the cone material to have excellent dynamic ductility at temperatures up to about 450°C. On reaching a target, the pressure developed between the jet tip and the forming crater can be as high as 10 Mbar (10 million atmospheres), several times the highest pressure predicted in the Earth's core.

Shaped charge is indeed an extraordinary phenomenon that is beyond the scale of normal physics, which explains why its fundamental theoretical mechanism is by no means fully understood.

The Explosively Formed Projectile (EFP)

Wide angle cones and other liner shapes such as plates or dishes do not jet, but give instead an explosively formed projectile or EFP, as illustrated in Figure 3. The projectile forms by dynamic plastic flow and has a velocity of 1-3 kms^{-1}. Target penetration is much less than that of a jet, but the hole diameter is larger with more armour backspall.

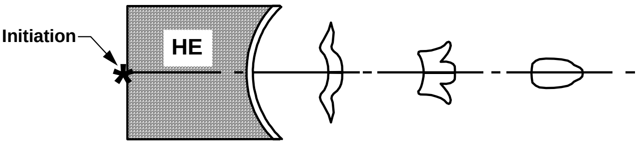

Figure 3. Stages in the development of an explosively formed projectile.

Hydrodynamic Flow

It is universally agreed that conical liner collapse and target penetration both occur by hydrodynamic flow**.** However, it has been established by X-ray diffraction that the jet is solid metal and not molten. Additionally, best estimates of jet temperature by incandescence colour suggest a mean value of about 450°C, and copper melts at 1083°C at atmospheric pressure. So the following conundrum is the first confusion:

> ***The jet appears to behave like a fluid, and yet it is known to be a solid.***

One recent theory that would help explain this is that the jet has a molten core but with a solid outer sheath (Cullis, DERA Fort Halstead, UK).

The target penetration flash X-ray of Figure 2 shows that hypervelocity hydrodynamic impact (unlike lower speed KE penetration) results in a mushroom head penetration, such that the hole diameter is larger than the penetrator diameter. The dynamic compressive yield stress of the target is exceeded by a factor of at least one thousand times, so that only the densities of the target and jet materials are important. Both materials flow as if they were fluids and the penetration event can be modelled quite accurately using the Bernoulli equation for incompressible flow to give the well known hydrodynamic penetration equation:

$$p = L\sqrt{\frac{\lambda\rho_j}{\rho_t}} \qquad (1)$$