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Note on Armour Steel Design—A Proposition

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Abstract. A theoretical approach to the ballistic penetration and armour development has been made and a single phase material with a computer evaluated optimum hardness has been proposed to give a superior performance as an armour.

A change in philosophy is required in the development of new armour material, the change being towards a theoretical approach to the ballistic penetration problem from energy stand point[1,2,3,4]. Theoretical approaches to ballistic penetration and armour development however could be complemented by materials development through ballistic testing programs.

The ballistic limits of homogeneous steel plates generally increase with hardness and thickness but a transition region often exists about 400 to 500 BHN wherein penetration depends on whether the projectile fractures or remains in tact. A complete understanding of penetration phenomena at high strain rates has yet to be attained. High hardness achieved by high carbon content/martensitic microstructures and low tempering temperatures or by face hardening enhances the resistance of steel targets to ballistic penetration. Thus when a projectile hits a target, it either gets stuck up in the target or perforates it, depending on its velocity and the thickness of the target. In the course of penetration the projectile loses its kinetic energy (K.E.). So a relation connecting K.E. of the projectile and the energy dissipated at the projectile target interface can be expressed as an ideal equation. An empirical formula developed in terms of the hardness of material gives the energy dissipated in ergs.

$$E_0 = 10^7 [- 2\times 10^1 + 3 \times 10^{-1} H_1 + 10^{-2} H_2 + 3 \times 10^{-4} H_1$$
$$+ 2 \times 10^{-7} H_2^2 + 24 \times 10^{-5} H_1 H_2] \text{ ergs}$$

and

$$H = \left[\frac{a_1 H_1 + a_2 H_2}{a_1 + a_2}\right] \tag{1}$$

$$[a_1 + a_2] = 100 \tag{2}$$

where H is the hardness of the target material. H_1 is the BHN of the matrix in the target material and H_2 is the BHN of the dispersed phase in the target material (for e.g., ferrite matrix and carbide dispersed phase in steel armour).

The K.E. lost by the projectile due to impact on the target is given by

$$E_0 = \frac{1}{2} \frac{S\rho_1}{S\rho_1 + a\rho_2} U^2 \tag{3}$$

where

$\rho_1 = 8$ gms/cc (target density)

$\rho_2 = 14$ gms/cc (projectile density)

$s = 2.5$ cms (thickness of the target)

$a = 0$ to 3 cms (distance of penetration)

and $U = 54{,}000$ cm per second to 96,000 cms per second (velocity of projectile considered)

Combining Eqns. (1) and (3), we have

$$U^2 = \frac{2(S\rho_1 + a\rho_2)}{S\rho_1} E_0 \tag{4}$$

A computer output has been obtained on steels for different values of U, a & H. An optimum matrix hardness H satisfying the required ballistic properties has been evaluated. The target material essentially consisting of a matrix with dispersed particles when subjected to experimental trials gave satisfactory results for lower ballistic limits but did not prove to be so for higher ballistic limits. The performance of a steel armour is limited by the occurrence of a thermo-mechanical instability known as adiabatic shear which leads to a reduction in penetration resistance for high strength armour[5,6,7]. This prompted us for considering single phase material for armour steel with the improved mechanical properties in terms of both resistance to adiabatic shear and strength to weight ratio. It appears now that a single phase material with the evaluated optimum hardness (400 BHN) and with slightly higher thickness would give superior performance as an armour. Work on the development of such an armour steel is in progress and the results so far obtained seem to indicate the correctness of our proposition.

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