Def Sci J, Vol 35, No 2, April 1985, pp 219-223

Science of Armour Materials

T. Balakrishna Bhat
Defence Metallurgical Research Laboratory, Hyderabad—500258.

Abstract. This article discusses some basic principles that underlie design of effective armour materials against various modes of attack.

1. Introduction

Armour materials play an important role in defence. The infantry uses armour to seek protection against small arms and fragments. The light combat vehicles use armour for protecting a collection of persons against similar attacks; while in a tank, total protection is sought against all known lethal weapons. A ship calls for an armour against missiles and torpedoes, while an aircraft needs an armour to protect at least its crew against high velocity fragments and bullets. The armour materials used in the various circumstances are varied, since an effective armour design involves some special features that enhance the efficacy of the armour against a particular mode of attack. Nevertheless, there are many scientific principles that are common to the design of all armour materials. This article discusses some basic principles that underlie design of materials effective for use as armour.

2. The Modes of Attack

The modes of attack on any armour can be broadly classified under four heads, (i) kinetic energy attack, (ii) momentum attack, (iii) shock wave attack, and (iv) diffused pressure pulse attack. Fig. 1 schematically depicts the attack and the damages they cause.

The bullets from rifles, fragments from bombs and shells or large calibre shots, normally impinge on armour materials and penetrate the armour. The impact velocity ranges from 0.6 to 1.8 km/sec. and is generally lower than the velocity of sound in solids. At these velocities, the induced stresses are of the order of the strength of solids and the efficacy of the armour is governed by its ability to absorb energy. The momentum of the projectile is rapidly transported to the supporting structures and does not play any important role in causing damage.

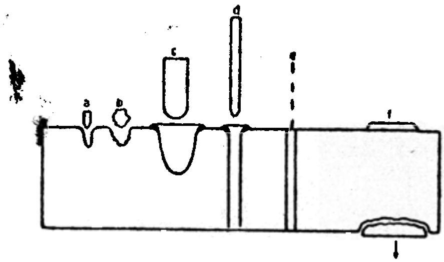

Figure 1. Schematic description of damage capabilities of some ammunitions. (a) 7.62 AP shot, (b) missile fragments, (c) 105 APDS shot, (d) 105 FSAPDS penetrator (e) hollow charge, 106 RCL, (f) HESH and (g) pressure pulse from mine.

A distinctly different mode of attack is the hollow charge attack. In this a high velocity jet is generated *insitu* by the missile on colliding with the target. The jet velocity is about 10 km/sec. and is higher than the velocity of sound in typical solids. At these high velocities the stresses generated far exceed the strength of even the strongest of solids and any target material behaves like a fluid. The ability of the material to resist such an attack is governed primarily by the inertia of the material and energy is absorbed primarily as kinetic energy of the moving target material near the area under attack rather than as energy of deformation or fracture. The momentum absorption is also extremely localised at the time of penetration. Fig. 2 schematically depicts the zones absorbing energy and momentum as a function of velocity.

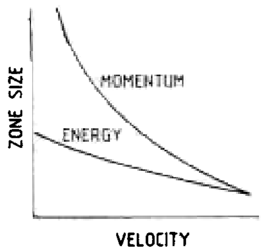

Figure 2. Schematic variation of process zone as a function of velocity for energy and momentum absorption.

Another mode of attack is through shock waves. An explosion in contact with the armour is a typical example of shock wave attack. A more diffuse form of attack is through an explosion not in contact or a mine in which a huge debris of fine powder-gas mixture impinges on the target to buckle or rupture the structure.

3. Armour Material Against Kinetic Energy Attack

An armour against kinetic energy attack can perform its function in three ways: (i) absorb the energy, (ii) make the shot absorb energy on itself, and (iii) turn the shot away. Although any armour can use all the three means to combat the attack, one of the three modes makes a dominant contribution to the efficacy of the armour.

3.1. *Energy Absorption*

Metallic armour materials absorb energy through deformation. In this case the total energy absorbed E depends on the product of flow stress σ strain $\in$ and the volume V participating in energy absorption.

$$E = \sigma \in V$$

The strength can be enhanced using conventional metallurgical techniques : Solid solution alloying, grain refinement, generation of dislocation substructures and incorporation of precipitates and dispersoids.

The volume V depends on the spread of the deformation zone during penetration. The spread depends on the plastic modulus or the slope of the stress-strain diagram in the plastic region, (Fig. 3). The larger the slope, the more rapid is the propagation of plastic wave and larger is the volume. Fine grain size and dispersoids enhance the plastic modulus.

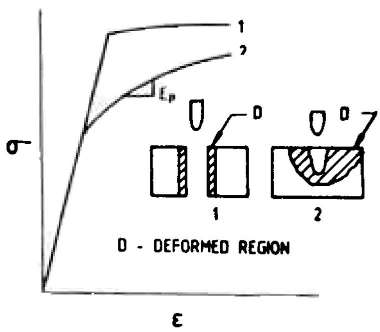

Figure 3. Role of plastic modulus in deciding the deformation zone size in armour material. The hatched area in the inset correspond to the area undergoing severe deformation.

The strain is normally governed by the geometry of penetration but can be terminated at lower values if the material begins to crack up or exhibit inhomogeneous flow.

Large strain rate gradients are common in penetration processes. It is important that the material be able to sustain the strain gradients without cracking up. This is possible only when the ductility rises with strain rate—an important quality of a good armour. The strength and ductility of three materials 1, 2 and 3 as a function of strain rate are shown in Fig. 4. Only material 2 is a good armour even though it is not the strongest and even though its ductility is about the same as those of the other two materials. A mark of distinction of material 2 over the other two is that its ductility rises with strain rate.

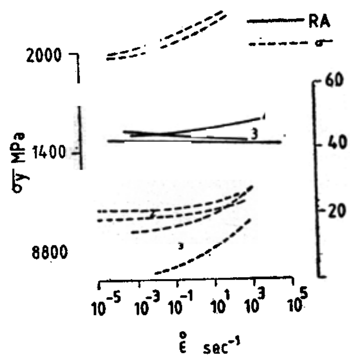

Figure 4. Role of strain rate sensitivity of ductility in armour behaviour. Flow stress, strain rate. Reduction in area RA for three different materials.

High hardness and impedence of the armour material can induce high stresses on the projectile which can absorb its energy on itself. Another ingeneous route to protection is to turn the shot away. Yield strength and impedence of the shot and the armour and the angle at which the shot strikes the armour are important parameters in this technique.

4. Materials Against Momentum Attack

In this mode of attack the penetration is governed primarily by the inertia of the target material and to a large extent the depth of damage is directly related to the inverse square root of material density. The areal density for protection varies as the square root of density. Thus low density armour, though thick, provides a light weight option for protection.

An important aspect of very high velocity collision is the momentum multiplication effect due to material splash back from the target (Fig. 5). The splash back

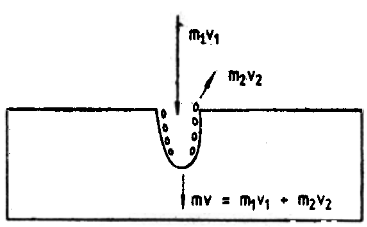

Figure 5. Momentum multiplication in high velocity momentum attack.

injects an additional momentum into the armour, thus increasing the damage. It is important to avoid this in an effective armour.

5. Armour Against Shock Waves

Shock waves travel with ease in homogenous materials but get dissipated by repeated internal reflection in inhomogeneous media. An ideal material against shock wave

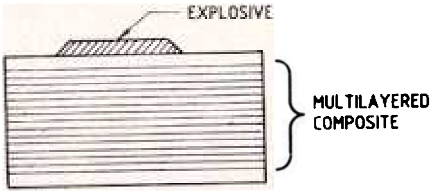

Figure 6. A multilayered composite to subdue shock waves.

attack is a multilayered composite that causes repeated reflections of the shock wave to dissipate it (Fig. 6).

6. Material Against Pressure Pulses

This is a relatively large duration, large area attack and causes no material penetration. Instead; bending, buckling and large scale movements predominate the terminal effects. An effective design against such an attack is an extension of the well known collapsing pipe method. A bundle of pipes stacked together will get crumpled severely to absorb energy. Maintaining a certain length to diameter ratio and wall thickness of the pipes is essential for the success of this route. A microanalog used for effective materials design is found in wood which is made of fine bundles of pipes, the pipe wall being wound with high strength fibrous material.

7 Conclusion

An armour calls for a materials design that combines a variety of conflicting properties. This has opened up a new field of composite armour materials.

Acknowledgement

The author is indebted to Dr. Raja Ramanna who has been a constant indirect source of inspiration.