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Effect of Clamping Rigidity of the Armour on Ballistic Performance

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ABSTRACT

Influence of the manner in which the armour plates are held during their ballistic testing on the armour performance, has been evaluated. One armour plate was clamped rigidly to the test stand while a second plate of identical composition, hardness, and dimensions was hung loosely from the target holder. Both these plates were impacted with the same type of projectiles and over the same impact velocity range. The nature of ballistic damage evaluated indicates that the manner in which the armour is held during ballistic testing has a negligible influence on its performance at least when the mass of the plate is substantially higher than that of the projectile.

1. INTRODUCTION

Evaluation of ballistic performance of potential armour materials requires the armour plate be tested against the projectile of interest over a range of impact velocities and impact angles. In such tests, the armour material to be tested is usually clamped rigidly on to a massive target holder. This target holder, apart from being suitable for accommodating the armour plate of required dimensions, usually has a provision to vary the impact angle, defined as the angle formed between the normal to the armour plate and the path of the projectile.

A natural question that arises with respect to the ballistic testing of armour plates is the extent to which it should be clamped to the target holder. The term 'rigid clamping' is rather ill-defined and the clamps used for holding the armour plate against the target holder can be tightened up to various torque levels in actual practice. Thus, it is important to understand the influence of the rigidity of the clamping on the ballistic performance of the armour plate. The results of a preliminary investigation carried out to characterise this aspect are reported in this paper.

However, the effect of rigidity of clamping of the armour plate on its ballistic performance can be properly evaluated only if a parameter which is very sensitive to small changes in armour performance is chosen in the first place. The commonly used ballistic limit velocity, defined as the minimum projectile velocity at which the armour plate is fully perforated, is not a proper parameter since it is subject to a significant statistical variation. Such a variation has been attributed to the increased resistance offered by the armour material to the penetrating projectile during the final stages of perforation[1,2]. The residual velocity of the projectile, measured after it perforates the armour plate, is very sensitive to small variations in the armour resistance. However, the measurement of this parameter was not possible with the experimental set-up used in the present investigation.

An alternative parameter which characterises very sensitively the resistance of the armour material is related to the blind, deep hole formed by the penetrating projectile at velocities below the ballistic limit. The depth of this hole (X) and its volume (U) are useful parameters in this regard and both can be evaluated as a function of impact velocity (V_p) at velocities below the ballistic limit. In the present investigation, the influence of the rigidity of clamping on armour performance has been evaluated on the basis of the parameters X and U.

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2. EXPERIMENTAL

Materials

A low alloy steel plate of thickness 20 mm, in the hot rolled condition, was used as the target plate. The hardness of the plate was around 350 HV and its lateral dimensions were 450 × 450 mm. The mass of the plate (m_t) was 31.8 kg. A 20 mm armour piercing steel projectile of 108 g with hardness of 650 HV and an ogive nose was used. The hardness of the projectile about a factor of two higher than that of the target plate, ensured that it did not undergo significant plastic deformation during its penetration into the armour plate.

2.2 Target Holder

A target holder was fabricated from a 5 mm thick mild steel angled iron. The base of the target holder was massive and was further anchored firmly in the hard ground. The armour plate was clamped firmly to this holder and one set of experiments was carried out which simulated rigid-clamping (Fig. 1(a)). Another set of experiments was carried out with the target plate hanging from the holder using a high tension 500 mm long steel wire which simulated the 'non-rigid' clamping situation (Fig. 1(b)). In both sets of experiments care was taken to ensure that the projectiles did not impact the hanging plate especially near its bottom edge.

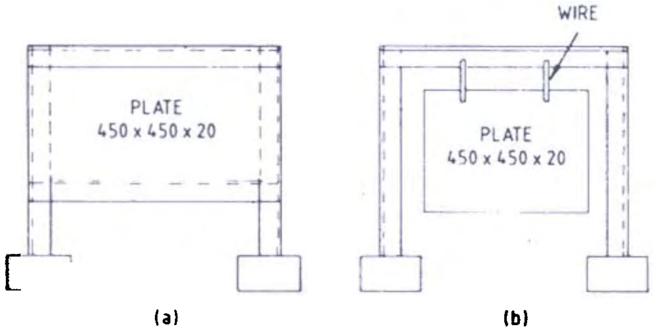

Figure 1. A schematic view of (a) rigid and (b) non-rigid clamping arrangements showing firing stands for normal angle of attack.

2.3 Test Details

Irrespective of the rigid-clamping or the hanging (non-rigid) arrangement, all the ballistic tests were conducted at zero obliquity, i.e., the projectile impacted the plates normally. A range of projectile velocities (V_p) was obtained by varying the propellant charge mass. The velocity of the projectile was measured using an aluminium foil digital timer system. It was also ensured, by proper laying of the gun, that the centre-to-centre distance between any two craters formed by the projectile impact was at least three times the diameter of the projectile.

The craters formed on the armour plates were then examined in detail. The depth of the craters (X) and their diameters on the entry side (D) were measured using a three-dimensional measuring and marking machine. The craters were then filled with incompressible plasticine of known density and their weight measured to obtain their volume (U).

The energy absorbed by the armour plate per unit volume, defined as the specific energy (E), was then computed using the equation

$$E = 0.5\, m_p V_p^2 / U \qquad (1)$$

In Eqn (1), 0.5 $m_p V_p^2$ represents the kinetic energy of the impacting projectile. E has units of strength and equals the hardness of the material if the inertial resistance of the target material becomes negligible.

3. RESULTS AND DISCUSSION

It is clear from Figs 2 and 3 that the rigidity of clamping has negligible influence on the armour performance as characterised by X and U. Figures 4 and 5 also show the manner in which the armour plate is held (clamped or hung) has no measurable influence on either D or E. This result can be rationalised on the basis of a simple theoretical analysis as discussed in the following paragraphs.

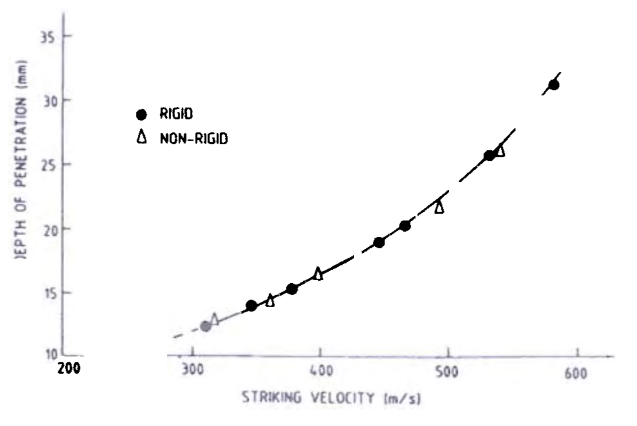

Figure 2. The variation of depth of penetration with impact velocity.

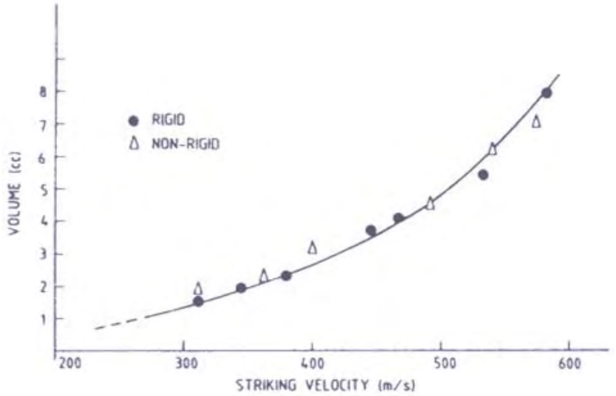

Figure 3. The variation of crater with impact velocity.

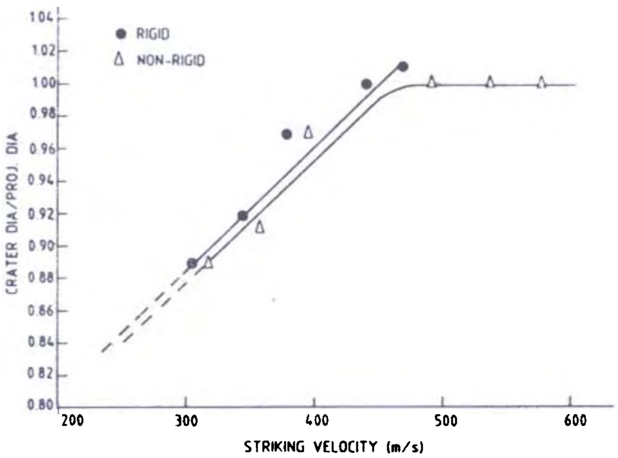

Figure 4. The variation of crater diameter normalised by projectile diameter with impact velocity.

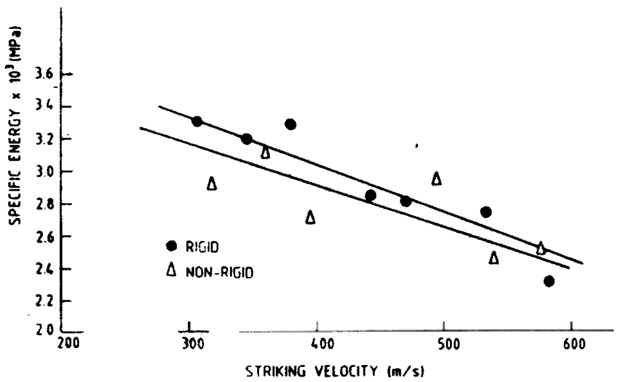

Figure 5. The variation of specific energy with impact velocity.

Let m_p, V_p and V_{pf} be the mass, initial velocity, and final velocity (after impact) of the projectile and m_t and V_{tf} be the mass and final velocity of the armour plate Then the coefficient of restitution (e) can be defined as

$$e = (V_{pf} - V_{tf}) / V_p \tag{2}$$

where $e = 1$ for purely elastic impact and $e = 0$ for fully plastic impact.

The conservation of momentum requires that

$$m_p V_p = m_p V_{pf} + m_t V_{tf} \tag{3}$$

The conservation of energy, kinetic energy in this case demands that

$$0.5\, m_p V_p^2 e^2 = 0.5\, m_p V_{pf}^2 + 0.5\, m_t V_{tf}^2 \tag{4}$$

Solving Eqns (3) and (4) one obtains

$$V_{tf} = (m_p V_p + e\, m_p V_p)/(m_p + m_t) \tag{5}$$

$$V_{pf} = (m_p V_p - e\, m_t V_p)/(m_p + m_t) \tag{6}$$

In this analysis, it is assumed that the armour plate is free to move and thus is appropriate to the tests conducted on hung armour plates. In the case of rigid clamping, V_{tf} is necessarily zero. In the case of non-rigid clamping, the kinetic energy of the moving plate equals $0.5\, m_t V_{tf}^2$ and the importance of this term in relation to the energy absorbed in plastic deformation is given by the ratio

$$R = 0.5\, m_t V_{tf}^2 / (0.5\, m_p V_p^2 (1 - e^2)) \tag{7}$$

The evaluation of R requires an estimate of e. An appropriate expression[3] for e is

$$e = .9\, H^{5/8} / E_e^{1/2} \rho_p^{1/8} V_p^{1/4} \tag{8}$$

where H is the projected area hardness of the steel, E_e is the effective elastic modulus of the projectile-armour plate system, and ρ_p is the density of the projectile.

In the present set of experiments utilising steel projectile against steel plate (H = 3730 MPa, E_e = 231 GPa and ρ_p = 7860 kg/m³), Eqn (8) simplifies to

$$e = 1.25 / V_p^{1/4} \quad (9)$$

As per Eqn (9), e equals 0.3 and 0.25 at V_p = 300 and 600 m/s respectively. With these values of e, the final velocity of the plate (V_{tf}) can be estimated as (m_t = 31.8 kg, m_p = 0.108 kg) 1.3 and 2.5 m/s. The ratio R, computed using the above values of e and V_{tf} equals 0.6 and 0.55 per cent at impact velocities of 300 and 600 m/s. To conclude, less than 1 per cent of the energy absorbed in the plastic deformation of the armour plate is transferred to it as kinetic energy even if it is completely free to move (for example, hanging). Thus, the manner in which the armour plate is held during ballistic testing should have negligible influence on the armour performance as observed experimentally.

Apart from the energy considerations enumerated above, the armour plate in the hanging mode should move a negligible distance during the impact process. A simple analysis of the $X - V_p$ data in Fig. 2 indicates that the time of impact is about 83.3 μs at 300 m/s and around 108.3 μs at 600 m/s. During this time period, the armour plate would have moved only 116.6 and 301.2 microns at the impact velocities of 300 and 600 m/s respectively even if it is assumed that the momentum of the projectile is transferred to the plate instantaneously on impact. The movement of the plate by such a small distance will have practically no effect on the projectile-plate interaction. However, the armour plate will continue to move even after the completion of the impact process and this distance may be quite large.

The predictions of the theoretical analysis have been shown to be consistent with the experimental observations. Thus, it is appropriate to predict on the basis of the same theoretical analysis, the experimental conditions under which the manner in which the armour plate is held will significantly influence its performance. The projectile velocity (V_p) and the ratio of the target plate to the projectile mass ($M = m_t/m_p$) are the two experimental variables and their influence on the ratio R (Eqn (10)) has been obtained by combining Eqns (5) and (7).

$$R = [\, M/(1 + M)^2 \,]\, [(1 + e)/(1 - e)\,] \quad (10)$$

Since e depends only weakly on the projectile velocity, R is negligibly influenced by the projectile velocity. Thus, the mass ratio M is the dominant variable. If it is assumed that a value of R, less than 5 per cent, satisfies the criterion of 'negligible influence of clamping force on ballistic performance', then Eqn (10) implies a minimum value of around 33 for M (assuming an average value of 0.275 for e). This corresponds to a minimum target plate mass of about 3.6 kg for the 20 mm projectile of mass 108 g. This mass in turn is equivalent to a very small steel plate of 150 × 150 × 20 mm size. Thus, it is very clear that for realistic values of M and projectile velocity, the manner in which the armour plate is held will not affect its performance during ballistic testing.

4. CONCLUSION

It can be concluded that the manner in which the armour is held during ballistic testing (rigid or non-rigid) has a negligible effect on its performance for a 20 mm projectile of mass 108 g.

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