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Study on Basic Mechanism of Reactive Armour

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ABSTRACT

Two basic mechanisms which operate in the functioning of reactive armour are presented. Both the explosive effect and cutting of metal plates by a jet have been investigated. The angle of attack and the confinement of the explosive have been found most significant factors in reducing the penetrating power of the jet. The effect of detonating explosives has been investigated with radiography. Some of the significant effects, like detonation of explosive by the impact of the jet, expansion of covering plates, disturbance in coherence and reduction in the penetration of the jet have been observed. It is found that the jet penetration in a stack of mild steel plates is reduced to 30 per cent of its blank penetration in present set-ups. A theoretical model has been conceived to study the interaction of moving plates and the jet. The critical thickness and surface cut in plates have been calculated.

1. INTRODUCTION

To meet the threats of modern antitank warheads, the armour of a main battle tank today consists of rolled homogeneous armour (RHA) and applique armour[1]. While the RHA provides a normal protection and a strong structural integrity to the tank, the applique armour enhances its protection level for defeating the modern antitank warheads. Applique armours are generally of two types, namely, (i) a reactive armour[2] and (ii) an inert armour. The inert applique armour is either a composite armour, which consists of material of different shock impedences, strengths and densities, or a spaced armour, which contains optimum air gaps in between the metal plates. The reactive armour, on the other hand, contains an explosive layer in between two metal plates. While composite armour reduces jet penetration due to variation in shock impedences of different materials used in this armour, the reactive armour reduces jet penetration by utilising the jet in cutting of moving metal plates and by disturbing the coherency of the jet by moving high density detonation products across it.

In this paper, two basic mechanisms which operate in the functioning of reactive armour, namely, jet perturbation by detonation products and metal cutting effect of the jet, are presented. The former mechanism is operative in the early stages of interaction between the jet and the reactive armour. To a good approximation, the effect of detonation products on jet penetration can be considered independent of jet direction, but the consumption of jet in cutting metal plates is very sensitive to the angle of attack of the jet on reactive armour.

2. JET PERTURBATION BY DETONATION PRODUCTS

When a hollow charge jet strikes the sandwich of reactive armour, as shown in Fig. 1, its explosive is initiated within microseconds, but the effect of detonation products on the jet commences a little later, probably due to the fact that, immediately after detonation, there is no space for the products to move. Later, when plates start moving, the products, having velocity and density comparable to that of jet, start colliding with the jet elements and this transverse impact of detonation products with the jet makes the latter to

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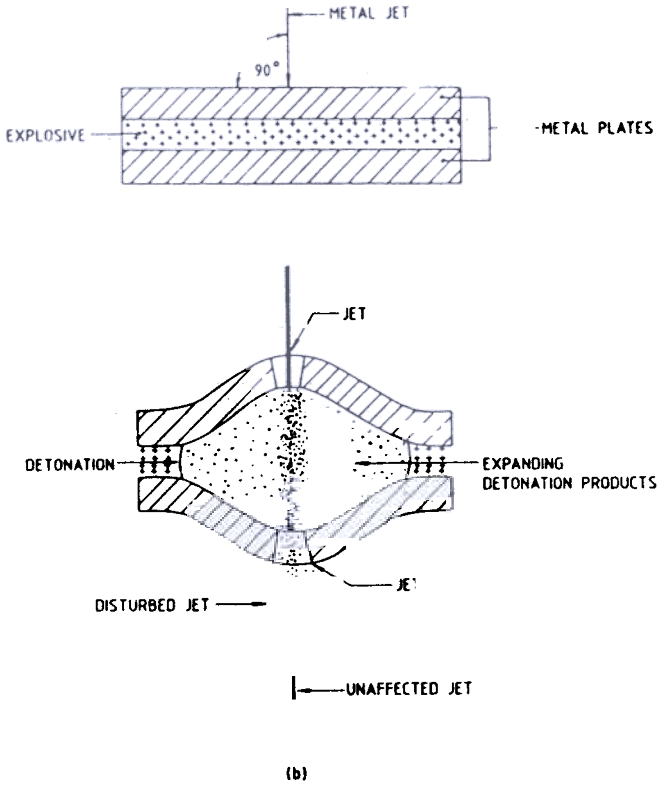

Figure 1. (a) Initial metal explosive assembly, (b) Response of metal-explosive assembly during detonation of explosive.

lose its coherency and linearity and hence reduces its penetration power.

When the plates move to a reasonable distance, and detonation products expand to a large extent, the effect of detonation products becomes weak and the jet passes undisturbed through this diluted region. The effect of detonation products on a shaped charge jet has been experimentally studied[3]. Figures 2-6, obtained from a similar experimental set-up using 73 mm calibre-shaped charge and sandwich of 25 mm thick metal plates of 150 × 150 sq mm, show that the jet remains disturbed over a period of 30 μs in case of a particular thickness of typical explosive. In the normal impact of the jet, the effect of jet neutralisation is solely due to explosive and lasts for a fraction of total life of the jet.

3. CONSUMPTION OF JET IN CUTTING OF METAL PLATE

A jet striking obliquely at a moving metal plate is shown in Fig. 7. This shows different sections of the jet impact on different points on the moving plate and hence make an extended crater in it. The extent of this crater depends on the plate velocity, the angle of impact

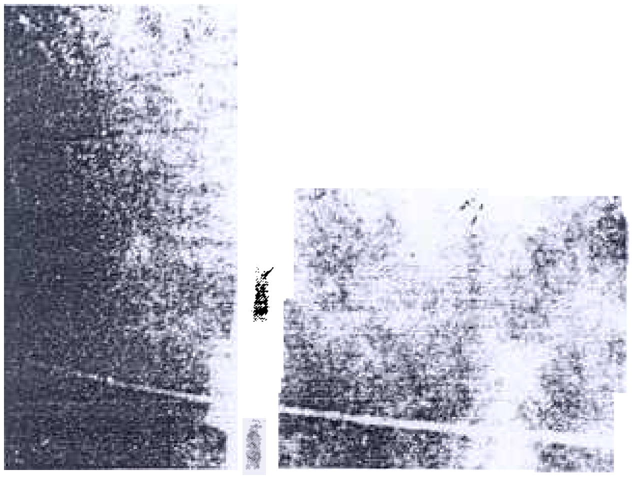

Figure 2. Radiograph of a shaped charge jet passing through metal plates without any explosive.

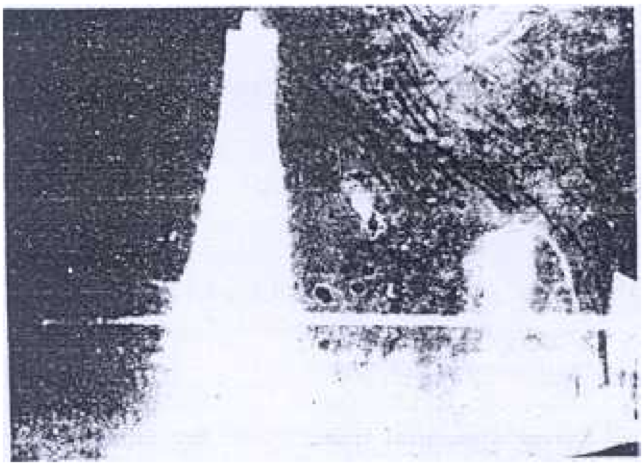

Figure 3. Radiograph of sandwich plates driven by thin layer of explosive at 30 μs.

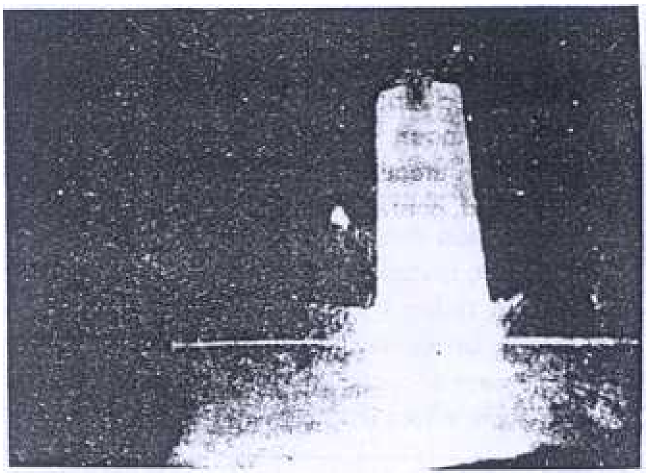

Figure 4. Radiograph of sandwich plates driven by thin layer of explosive at 35 μs.

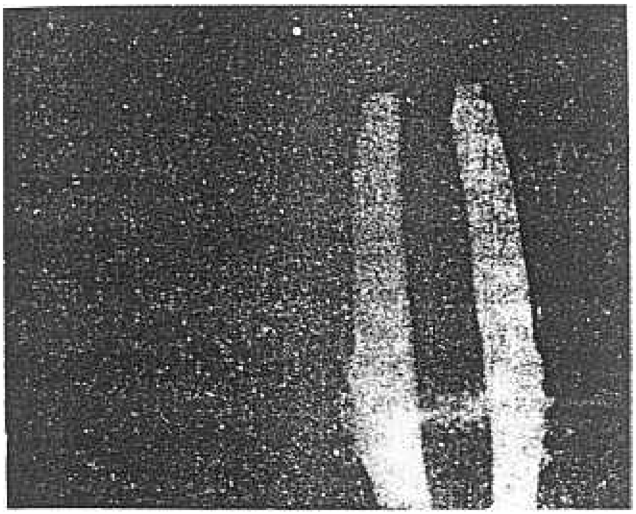

Figure 5. **Radiograph of sandwich plates driven by thin layer of explosive at 60 μs.**

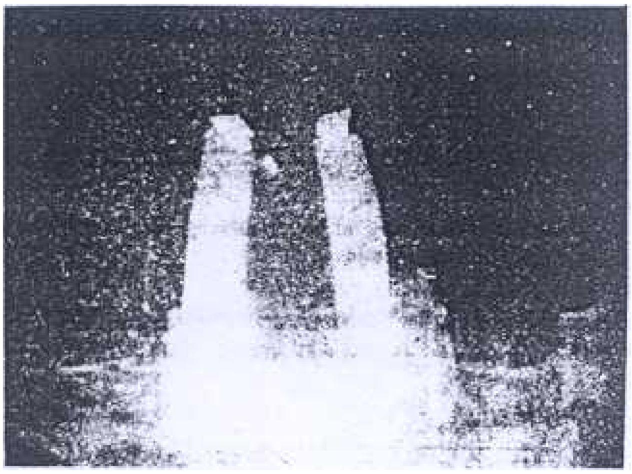

Figure 6. **Radiograph of sandwich plates driven by thin layer of explosive at 75 μs.**

and the duration of jet impact. If the plate velocity and its thickness are optimised then one can consume entire length of jet in very small thickness of a moving plate.

3.1 Plate Motion

In reactive armour, the plate is accelerated by the detonation of a thin layer of an explosive in its contact. Plate motion by cylindrical charges has earlier been studied by various investigators[4,5,6] but the motion of metal plates, accelerated by thin layer of explosive, has recently been studied by the author[7].

Based on assumptions of uniform pressure and density of detonation products between the plates, a relation for the velocity of undeforming plates has been derived as

$$U_p^2 = \frac{(2D^2/\gamma^2-1)\,.\,(\gamma/\gamma+1)^\gamma}{(1+2m/C)} \qquad (1$$

where U_p is plate velocity (specific heat ratio o detonation products), C/M is charge-to-metal mass rati and D is detonation velocity of the explosive. The plat velocities obtained from relation (1) have bee compared with experimental values in Fig. 8.

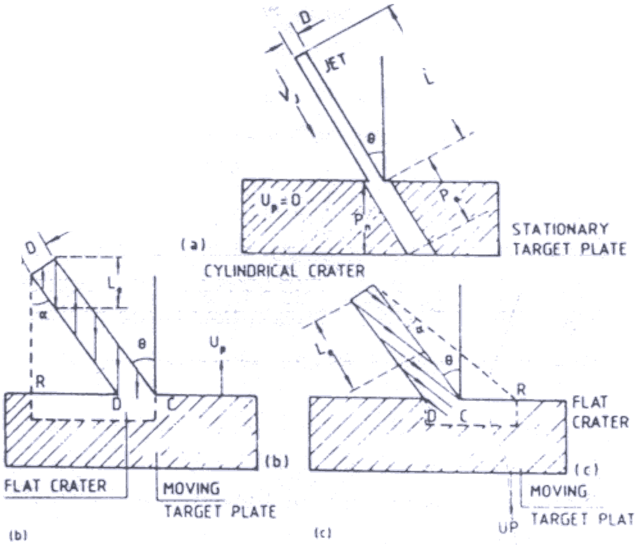

Figure 7. Conversion of total length of the jet L into many effecti lengths due to target motion.

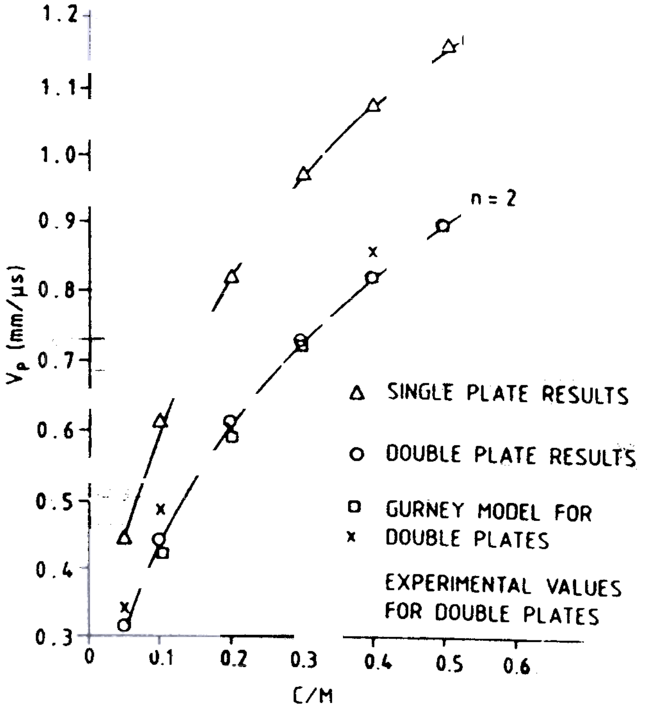

Figure 8. **Comparison of the oretical and experimental flyer plai velocities U_p at different charge to metal mass ratio (c/n in sandwich geometries.**

3.2 Effect of Moving Plate on Jet of Constant Velocity and Diameter

When a jet of finite diameter and constant velocity strikes a stationary target, it produces a cylindrical crater. But, in case of a moving target, the depth of the crater produced will depend upon the effective length of the jet impacting at a given point of the target. this effective length is decided by the diameter, the velocity of the jet element, the target velocity and the angle of jet impact.

Yadav[10] derived an analytical expression to obtain this thickness of the target plate, P_n as

$$P_n = \frac{D_j V_j}{} \left(\frac{\lambda \rho_j}{\rho_T} \right)^{1/2} \tag{2}$$

where D_j, V_j and ρ_j denote the diameter, tip velocity and density of the jet, ρ_T represents the density of the target and λ is a constant having value one for a continuous jet and two for a broken jet. In relation (2), θ is the angle of attack which is defined as the angle between the direction of the jet and that of the plate normal.

The surface cut X in the moving plate has also been obtained as

$$X = \frac{L\, U_P \operatorname{Sin} \theta}{V_j \operatorname{Cos} \theta \pm U_p} \tag{3}$$

where L is the complete length of the jet and negative and positive signs are used for downward and upward plate motions, respectively.

3.3 Effect of Real Jet on Moving Plate

In real jets, there is a velocity gradient along the jet length. The jet, therefore, elongates during propagation and its length does not remain constant at all stand-off distances. Also, on impacting a plate of finite strength, it produces hydrodynamically a hole of diameter greater than that of the jet. The diameter of the crater dp is then given as[9]

$$dP = D_j V_{jH} \left(0.5 K_p \sqrt{\rho_j \rho_P} \right)^{1/2} \tag{4}$$

where V_{jH} is hitting velocity and K_p is a crater constant determined experimentally, and defined as the volume excavated by unit amount of kinetic energy of the jet.

When a jet impacts at some point of the moving of the plate, a crater of certain diameter and depth is produced as shown in Fig. 9. Before the point of impact goes out of this crater, the jet penetrates certain depth of the plate. If the thickness of the plate is more than this depth of penetration, then the jet is consumed by the plate and no jet element goes out of the moving plate.

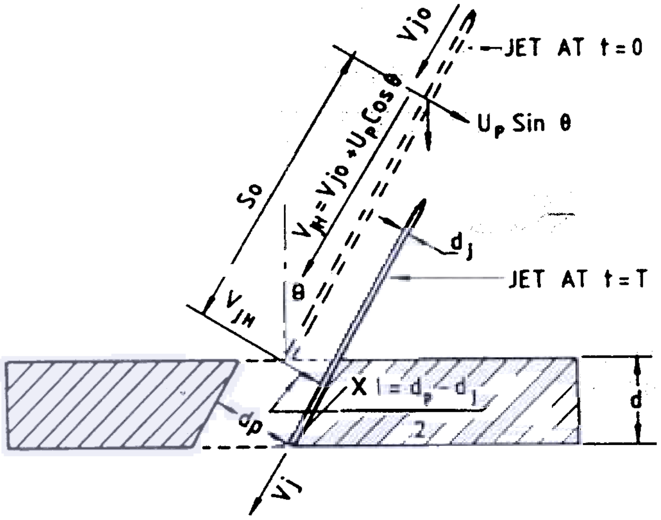

Figure 9. **Transvers shifting of jet in moving coordinates during penetration of the plate.**

Recently, Yadav[10], derived the expression for critical thickness of the metal plate as,

$$d = \frac{K D_j V_{jH}}{U_P \tan \theta} \tag{5}$$

where

$$K = \frac{\gamma_P}{2(1+\rho_P)} \left[V_{jH} \left(1/2\, K_P \sqrt{\rho_j \rho_P} \right)^{1/2} - 1 \right]$$

and $\gamma_P = \sqrt{\dfrac{\rho_j}{\gamma_P}}$

It is interesting to note that critical thickness of the plate is approximately equal to the product of initial rate of jet penetration and the time taken by the jet to shift through the initial crater.

If the plate is accelerated by a thin sheet of explosive sandwiched between the plates then the velocity of the plate U_p is given by relation (1) and therefore one can find the final expression for critical thickness of the plate as,

$$D_{min} \left\{ \frac{\gamma_P D_j V_{jH}}{2(\gamma_P H_x)} \left(\frac{2\rho_P}{\rho_x H_x} \right) \tan\theta \right) V_{jH} \left(0.5 K_P \sqrt{\rho_j \rho_P}\right)^{1/2} - 1 \Big] \Big\} \quad \text{for } \frac{2mc}{C} \tag{6}$$

It can be seen from this expression that the minimum thickness of the plate D_{min} which is just sufficient to consume a jet, strongly depends on the angle of impact θ. It also decreases with the increasing angle of impact. If the angle of impact approaches zero, then the jet shifting time, $(d_p - d_j)/2\ U_p \mathrm{Sin}\ \theta$ approaches an infinite value. This implies that complete length of jet passes through the initial crater itself.

In this case, shifting of point of impact can be given by the formula,

where

$$X = \frac{L\, U_P \,\mathrm{Sin}\,\theta}{V_{jT}\,\mathrm{Cos}\,\theta \pm U_P} \tag{7}$$

where V_{jT} is tail velocity of the jet, and distance moved by the plate along the normal direction is given by

$$Z = \frac{L\, U_P \,\mathrm{Cos}\,\theta}{V_{jT}\,\mathrm{Cos}\,\theta \pm U_P} \tag{8}$$

Table 1 shows the parameters of the plate, the explosive and the jet, used in the calculation of the critical dimensions of the moving plate and Table 2 shows the results of typical calculations carried out for mild steel plate and copper jet interaction. The explosive sheets of 5 mm and 10 mm thicknesses have been used in these calculations.

Figure 10 depicts the variation of critical plate thickness, D_{min} with angle of jet impact, θ for mild steel and aluminium alloy plates. The critical thickness monotonically decreases with the increasing angle of jet impact.

Figure 11 graphically represents the dependence of critical plate thickness D_{min} with jet tip velocity at an

Table 1 Constants of plate, jet and explosive used in calculations of critical parameters

	Plate		Jet			Explosive		
Material	Density (g/cc)	Crater efficiency factor k_p rg	Jet dia d_n (mm)	Density ρ_j (g/cc)	Cut off velocity V_jT (mm/μs)	Density ρ_T (g/cc)	Velocity of detonation (D) (mm/μ)	Adiabatic exponent of detonation products (γ)
Aluminium alloy	2.785	0 × 10		8.9	2.0	28		2.8
Mild steel	7.85	7 × 10		8.9	2.0	28		

Table 2 Critical parameters of the plate moving upward for different jet velocities using following data

d_j = 2mm, ρ_j = 8.9 g/cc, ρ_T = 7.85 g/cc, $K_p = 20 \times 10^{-12}$ cc/erg,
θ = 60, $D = 6.3 \times 10^5$ cm/s, Hx = 1 cm,
ρ = 1.28 g/cc, γ = 2.8, So = 34 cm

Jet velocity V_j (mm/μs)	ngle	Criticle plate thickness	Plate velocity U_p (mm/μs)	xplosive metal mass ratio (c/m)
9	60	26.336	0.384	0.06
8	60		0.472	0.09
7	60	10.42	0.597	0.156
6	60	5.979	0.766	0.2704
	60		0.992	0.4987
	60	.628		0.9754
	60	.748	1.577	2.032
	60	276	1.924	6.021

angle of impact, 60°. Higher density of the plate material and higher explosive thickness for plate acceleration result in lower critical plate thickness.

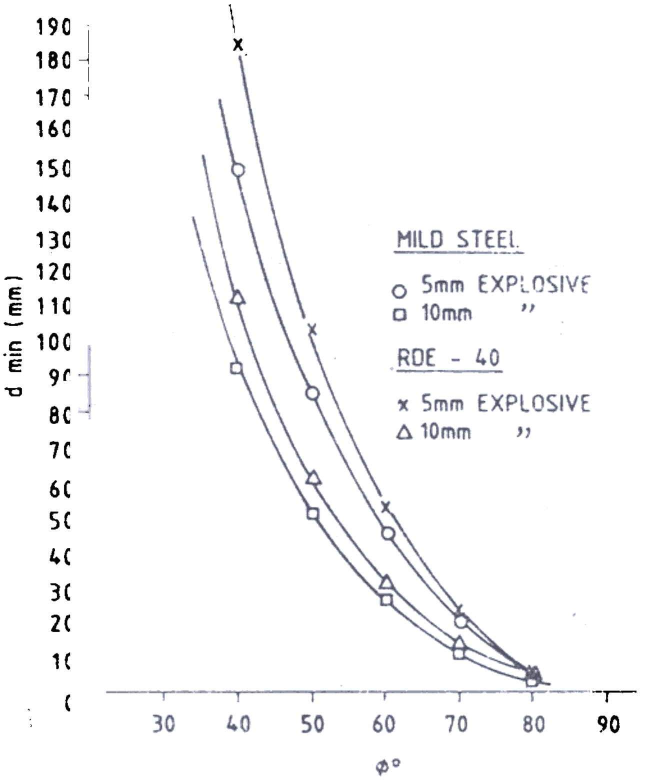

Figure 10. Variation in critical plate thickness (D_{min}) with angle of jet impact (θ) for V_jo = 9.

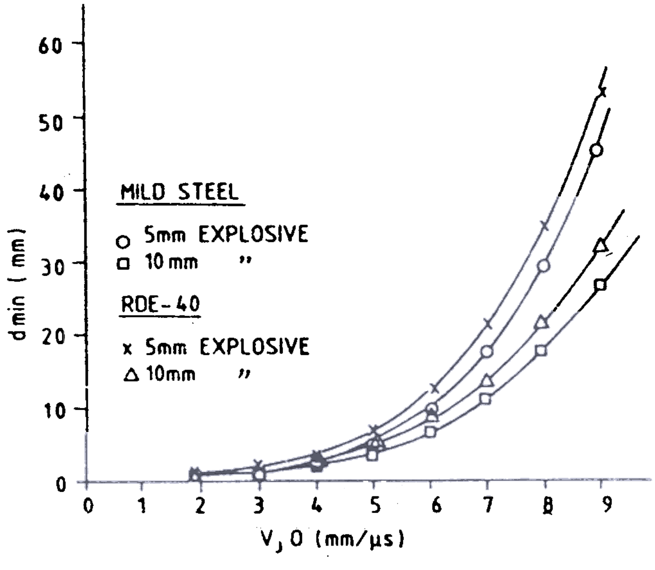

Figure 11 Variation in critical plate thickness (D_{min} with jet tip velocity V_jo at angle of impact, = 60°.

4. CONCLUSIONS

Critical thickness of a metal plate, accelerated by an explosive charge, and moving across the shaped charge jet, depends strongly on the angle of impact, jet and plate velocities and dynamic strength of the plate. Greater thickness is required to block faster jets. The critical thickness however reduces with increases in the strength and density of the plate.

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