

A NOTE ON THE BEHIND ARMOUR EFFECTS FROM PERFORATED ALUMINA / ALUMINIUM TARGETS

P. J. HAZELL, N. A. FELLOWS and J. G. HETHERINGTON

Cranfield University, Royal Military College of Science,
Shrivenham, Swindon, SN6 8LA, UK.

Summary - A thin, ceramic-faced armour, separated from a thick metal block, has been subjected to high velocity impact by a 6.35mm diameter steel sphere. Experimental work was carried out which compared firings into ceramic-faced aluminium armour, separated from thick aluminium 'witness' blocks, with firings into the thick aluminium blocks alone. The depth of penetration and the area of damage were measured and an estimated percentage weight saving due to the inclusion of the ceramic-faced armour was calculated at varying velocity. This note yields useful information for the design and application of ceramic appliqué systems.

NOTATION

a	thickness of the aluminium thin plate
c	thickness of the ceramic
r	penetration depth into the aluminium block with the ceramic-faced aluminium armour
x	penetration depth into the aluminium block without the ceramic-faced aluminium armour
A_{aa}	target area of the aluminium thin plate
A_c	target area of the ceramic
A_{ab}	target area of the aluminium block
WS	weight saving due to the introduction of a ceramic-faced aluminium armour
ρ_{aa}	density of the aluminium thin plate
ρ_{ab}	density of the aluminium block
ρ_c	density of the ceramic

INTRODUCTION

It has long been accepted that ceramic materials can play an important part in ballistic protection. Their high compressive strength and low density make them ideal candidates for armour systems. A limitation of using ceramic as armour is its brittle nature, requiring only a small fraction of the impact energy to fracture [1], and poor multi-hit capability. Hence lightweight ceramic armour systems generally consist of a ceramic tile bonded to a ductile backing plate of high specific strength. Although the majority of research has focused on the prevention of perforation, an increasing concern over the past few years is the effect of behind-armour debris on a structure set at a distance from the armour. Perforation of such armours results in small fragments travelling at high velocity [2] which can cause damage to the protected structure.

The aim of this work is to investigate the damage caused by behind-armour debris from a steel sphere perforating a ceramic-faced aluminium armour. Thick aluminium witness blocks were used to assess the damage.

EXPERIMENTAL SET-UP

To evaluate the performance of ceramic-faced aluminium armour, for impacts in the range 700m/s to 3000 m/s, firings were carried out using a 7.62 mm rifle and a two stage light gas gun.

A sabotted round was made up for firing from a standard 7.62 mm rifle to achieve relatively low velocities. The sabot, which consists of an aluminium support plate and

a polycarbonate pusher, was designed to propel the one gramme spherical steel projectile used in the two-stage, light-gas gun.

The performance of the armour was assessed by comparing the damage done to an aluminium witness block when firing with and without the armour in place. A jig was designed in order to ensure that the spacing between the armour and aluminium witness block was consistent from firing to firing (Figure 1).

The ceramic-faced armour, consisting of a sheet of 4 mm alumina (Sintox FA) bonded to a 2 mm aluminium (5083) backing plate, was fixed into the jig so that a gap of 30 mm existed between the aluminium back of the armour and the aluminium (6082 T6) block. To reduce edge effects [3], the ceramic armour had a target area of 100 mm by 100 mm and the aluminium block was a 100mm cube.

A screw-threaded spigot was incorporated into the jig to clamp the block to the front steel plate. This steel plate had a 80mm square hole, to allow the projectile to pass through and impact the block.

Figure 1: Schematic of target, aluminium block and jig.

The material properties of the metallic materials used in the experiments are given below in Table 1.

Table 1.

RESULTS

Two sets of experiments were performed using the above experimental set-up. The first set of experiments entailed firing into the ceramic-faced aluminium and examining the effect on the witness block set at a distance behind the armour. The second set of experiments entailed firing into the aluminium witness block alone.

Depth of Penetration Measurements

Both sets of experiments resulted in the aluminium witness block being penetrated. The aluminium blocks were sectioned and the damaged zone was measured with a travelling microscope. The depth of penetration (DOP) for each case is shown in Figure 2.

Figure 2: Depth of Penetration measurements for the aluminium block with and without the ceramic-faced armour.

It will be seen from Figure 2 that, for firings without the ceramic armour in place, a rapid drop in penetration is observed at velocities above 1800m/s. This is due to the brittle nature of the projectile used in this experimental programme. At 1509m/s the post impact crater is very long and thin (Figure 3a) and the projectile is clearly visible. A single fracture crosses the diameter of the sphere. At velocities above 1800m/s the crater is shallow (Figure 3b), with a mushroomed end and there is no visible evidence of the projectile. These observations are characteristic of projectile break up and erosion. Using Energy Dispersive X-Ray Analysis within the crater, small deposits of the projectile material were revealed on the crater wall. No projectile fragments were recovered. It is interesting to note that the step change

observed in Figure 2 is not mirrored in Figure 4. This indicates that on impact, the diameter of the crater measured at the front surface of the aluminium block is not greatly affected by the break-up of the projectile. Instead, the incoherent nature of the projectile will cause the crater to mushroom as fragments separate and erode. The projectiles' penetrative ability will therefore be reduced.

Figure 3a,b: Comparison of crater shape showing the effect of projectile fragmentation.

Spread of Damage Measurements

The damaged zone on the aluminium witness block was observed to be approximately circular and so the diameter of the zone was adopted as a measure of the spread of damage. Figure 4 describes the spread of damage observed on the witness block as a function of impact velocity for each of two configurations: with and without the ceramic-faced armour in place.

Figure 4: Spread of damage measurements for the aluminium block with and without the ceramic-faced armour.

It can be seen from Figure 4 that, throughout the velocity range, the spread of damage is *greater* with the ceramic armour in place than without. The rate of increase with velocity is also greater with the ceramic-faced armour in place.

DISCUSSION

Figures 5 and 7 describe the effect on the witness block of shielding it with the ceramic-faced armour. For depth of penetration and damaged area, a graph is plotted of the change in the parameter resulting from the inclusion of the ceramic-faced armour.

Figure 5: Reduction in penetration depth resulting from inclusion of the ceramic-faced armour.

As can be seen from Figure 5, the reduction in penetration, resulting from including the ceramic-faced armour, increases with increasing impact velocity up to approximately 1800m/s, when, due to shattering of the projectile, a negative step change occurs. Including a ceramic-faced armour, induces fragmentation even at low velocities due to the high hardness and high compressive strength of the ceramic. Clearly, if the sub-structure causes fragmentation to the projectile then the advantages of applying a ceramic armour are reduced.

A measure of the percentage weight saving resulting from the inclusion of the ceramic-faced armour system can be derived from Bless *et al* [3]. For the Aluminium block alone, the required mass required to stop a projectile can be estimated by:

$$\rho_{ab} A_{ab} x \quad (1)$$

Also, the mass of the material required to stop a projectile which has perforated a ceramic-faced armour can be approximated by:

$$\rho_c A_c c + \rho_{aa} A_{aa} a + \rho_{ab} A_{ab} r \quad (2)$$

In this experimental programme $A_c = A_{aa} = A_{ab}$, therefore the estimated % weight saving achieved by including a ceramic-faced armour is given by:

$$WS = \left[1 - \left(\frac{\rho_c c + \rho_{aa} a + \rho_{ab} r}{\rho_{ab} x} \right) \right] \times 100\% \quad (3)$$

It should be noted that Equation 3 provides an approximation of the % weight saving because the depth of penetration in a thick target will always be less than the thickness of target necessary to stop the projectile.

This relationship can be used with various appliqué systems and threat types to compare performance. For this experimental programme the relationship is plotted against velocity in Figure 6.

Figure 6: Percentage weight saving resulting from inclusion of the ceramic-faced armour.

Including a ceramic-faced armour results in an effective weight saving of up to 50% at 1800m/s, after which the advantage of applying such an appliqué armour is dramatically reduced.

In contrast, Figure 7 shows the area of damage is larger with the ceramic armour in place than without, due to the spread of debris.

Figure 7: Increase in the area of damage resulting from inclusion of the ceramic-faced armour.

Moreover, the difference in the area of debris spread is shown to rapidly increase with increasing velocity (Figure 7). Firing into an aluminium block alone results in a relatively small area of front surface damage (i.e. the area of the hole). Increasing the velocity of impact on the ceramic-faced aluminium results in an increasing degree of petalling of the back plate and hence spread of ceramic debris (Figure 8).

Figure 8a,b: Comparison of the spread of damage with and without the ceramic-faced armour.

CONCLUDING REMARKS

It can be seen that the inclusion of a ceramic-faced aluminium armour separated from an aluminium block has reduced penetration substantially. However, this is at a cost of increased damage area. At high velocities the reduction in the depth of penetration offered by the ceramic-faced armour becomes less when, without the armour, the projectile fragments on direct impact with the aluminium block.

The weight saving achieved by using ceramic-faced aluminium armour is dependent on the velocity of impact and threat type. In this programme of study, due to projectile

fragmentation, the weight saving achieved was significantly lower for velocities above 1800 m/s.

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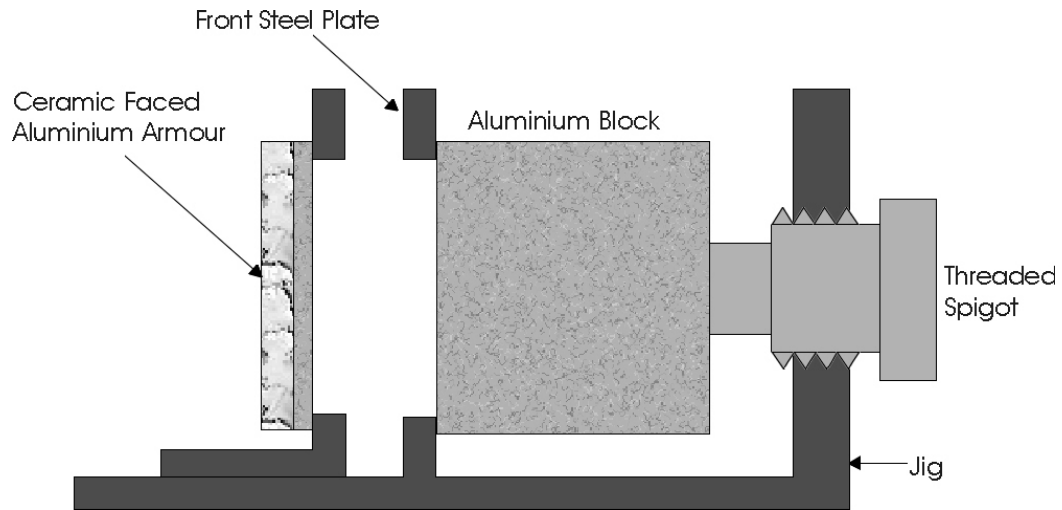


Figure 1: Schematic of target, aluminium block and jig.

Table 1.

	Steel Sphere	Thin Plate	Witness Block
Material	SAE 52100	ASME 5083	ASME 6082 T6
Dimensions (mm)	Ø 6.35	100×100×2	100×100×100
Density (Kg/m ³)	7810	2660	2710
Yield Strength (MPa)	1420	145	257

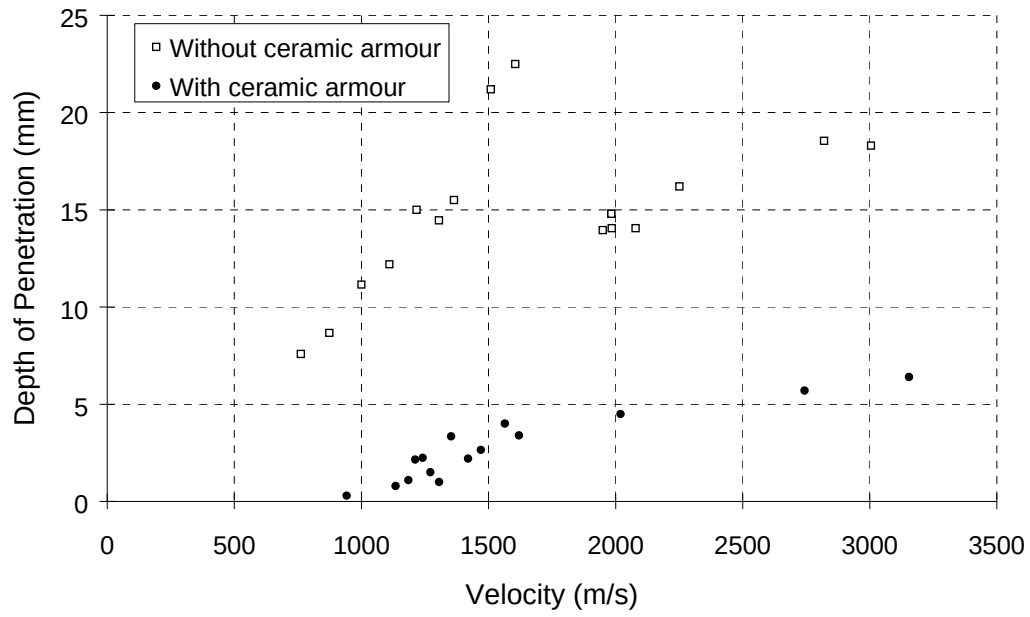


Figure 2: Depth of Penetration measurements for the aluminium block with and without the ceramic-faced armour.

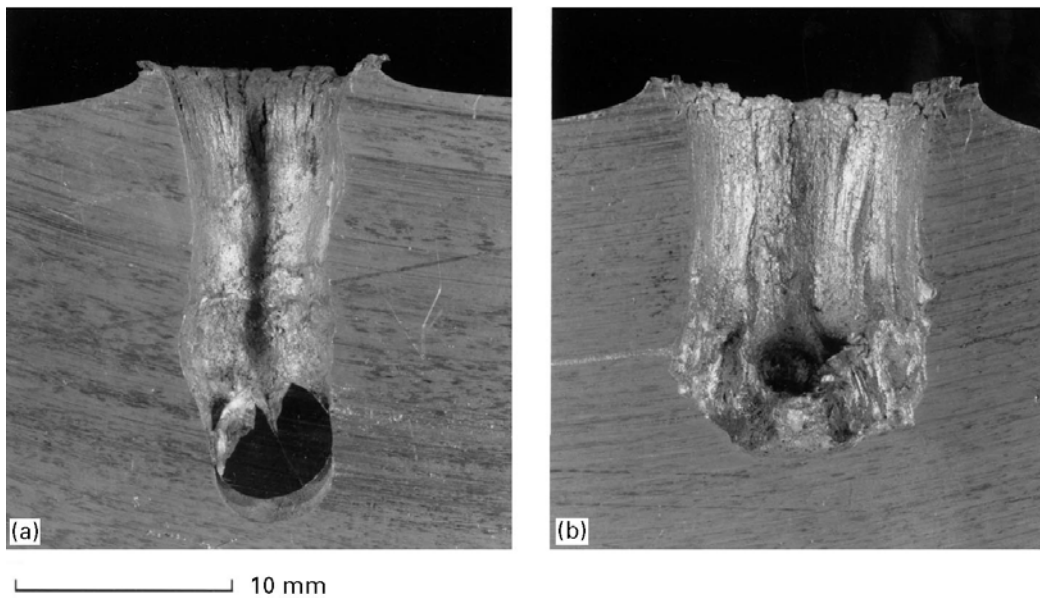


Figure 3: Comparison of crater shape showing the effect of projectile fragmentation.

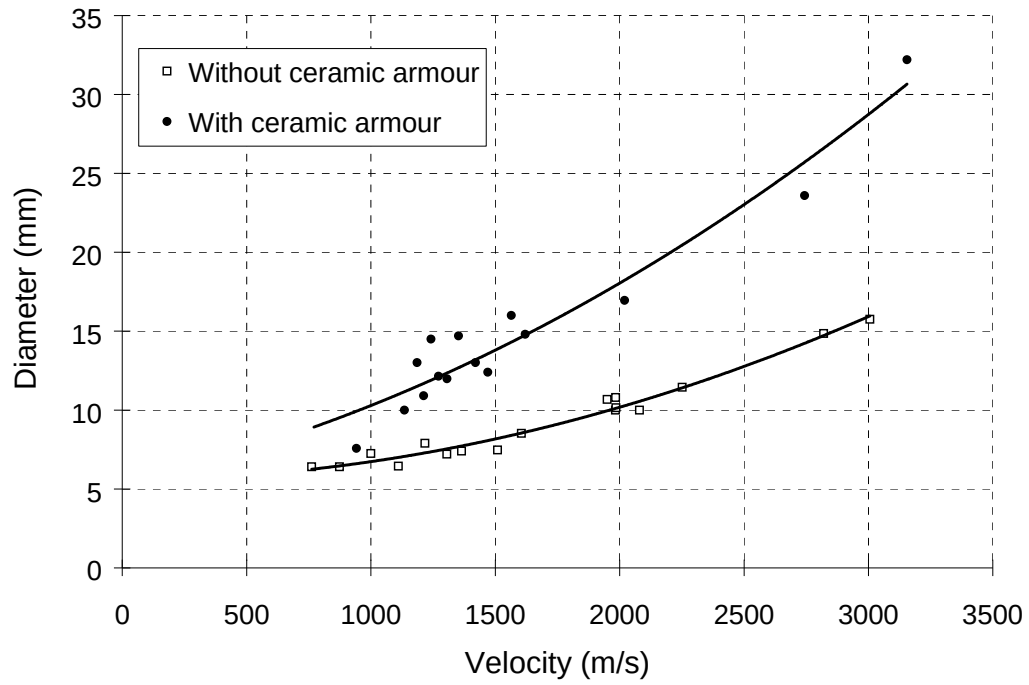


Figure 4: Spread of damage measurements for the aluminium block with and without the ceramic-faced armour.

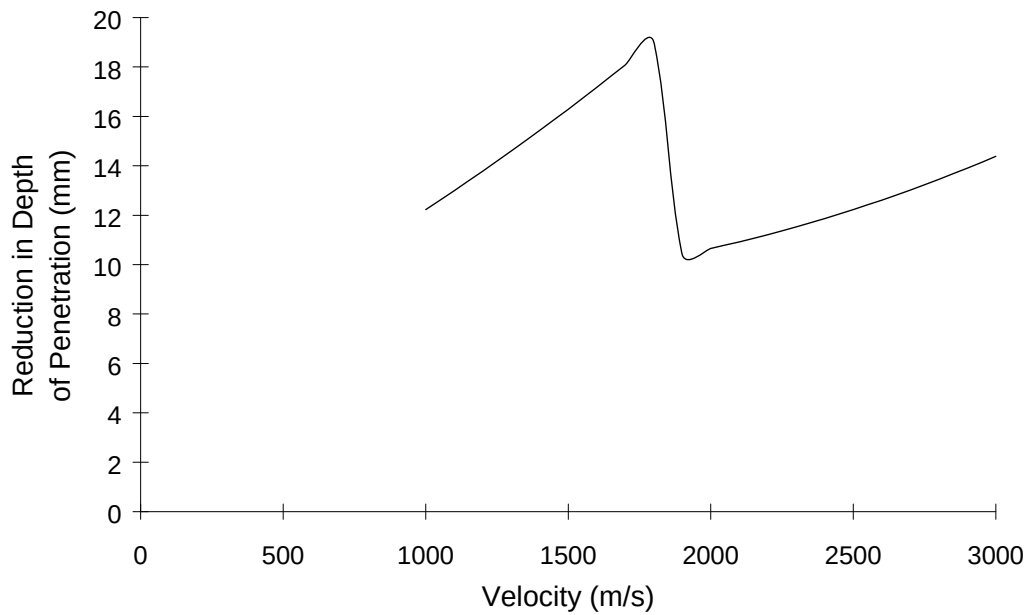


Figure 5: Reduction in penetration depth resulting from inclusion of the ceramic-faced armour.

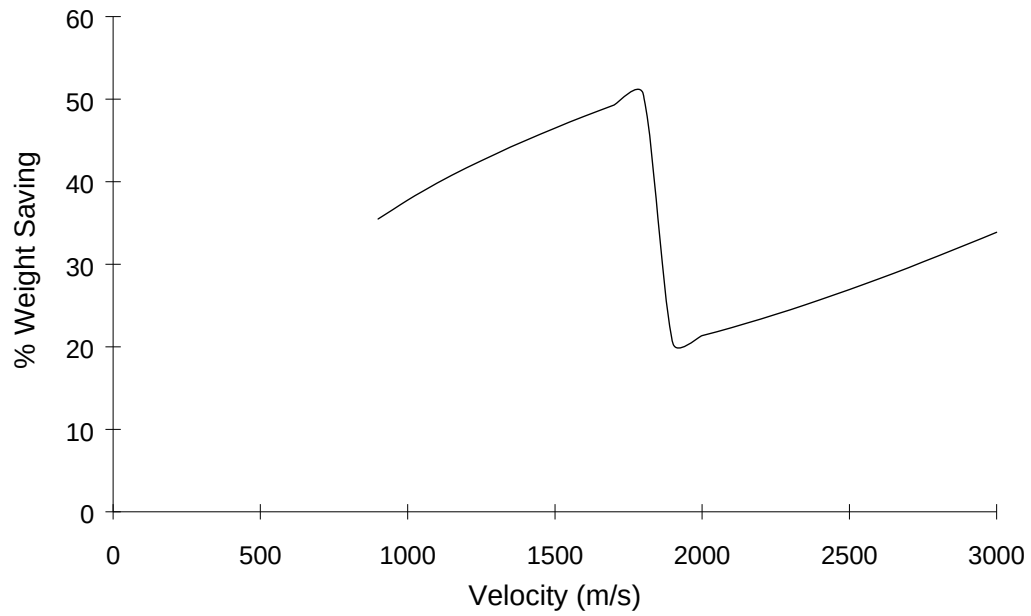


Figure 6: Percentage weight saving resulting from inclusion of the ceramic-faced armour.

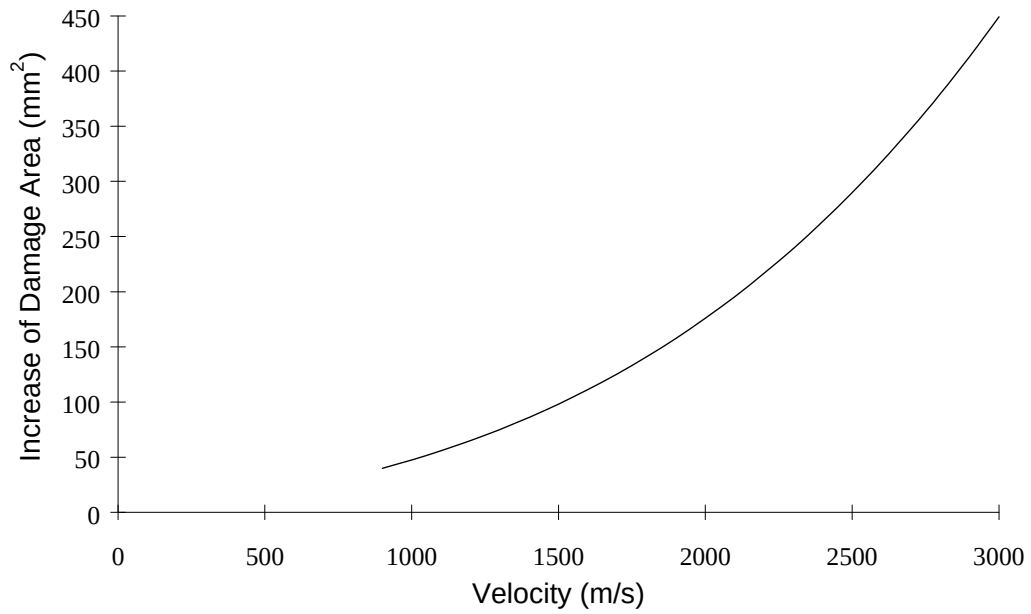


Figure 7: Increase in the area of damage resulting from inclusion of the ceramic-faced armour.

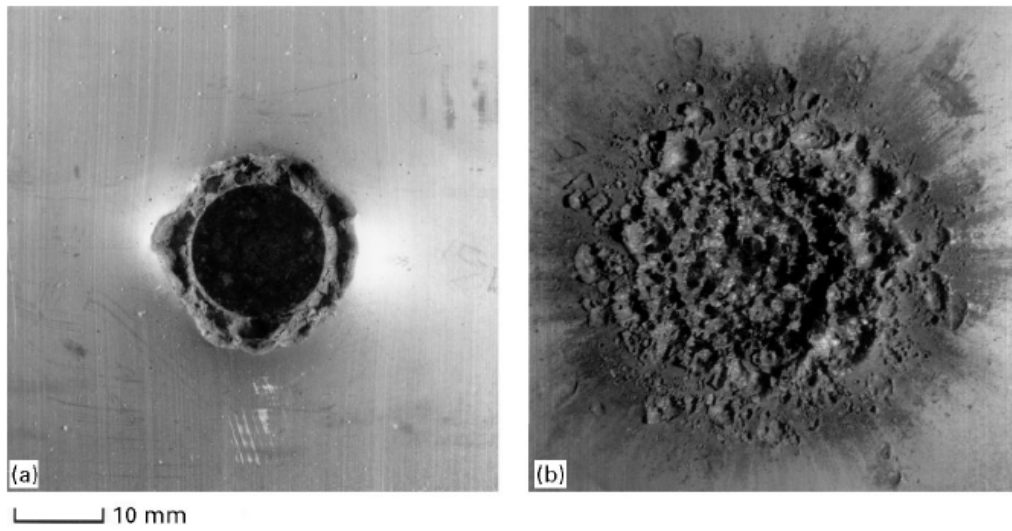


Figure 8 (a,b): Comparison of the spread of damage with and without the ceramic-faced armour.



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