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AN EXPERIMENTAL INVESTIGATION OF INTERFACE DEFEAT AT EXTENDED INTERACTION TIME

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In the experiments on interface defeat, which have been published, the process has normally been monitored only for tens of microseconds. Since the interaction time of a tank gun long rod projectile would be of the order of hundreds of microseconds, an experimental investigation has been undertaken to investigate whether interface defeat can be obtained for such long time intervals. It can for instance be argued that there exists an upper limit for the time that interface defeat could prevail due to the specific damage mechanisms of ceramic materials. This would mean that interface defeat could exist only for small projectiles, not for large ones. However, the results presented here show that interface defeat can be sustained for hundreds of microseconds. It is concluded that, in principle, it should be possible to obtain interface defeat even for full-scale tank gun long rod projectiles.

INTRODUCTION

It is possible to design ceramic armour systems capable of defeating ordnance velocity projectiles on the surface of the ceramic [1]. This capability, called interface defeat, means that the projectile material is forced to flow radially outwards on the surface of the ceramic without significant penetration. When the surface load generated by the projectile exceeds a critical value, at a critical impact velocity of the projectile, a transition between interface defeat and normal penetration behaviour occurs [2].

The phenomenon of interface defeat was first described by Hauver et al. [1] in 1993. Since then a number of papers have been published on this topic, see e.g. [2–5]. In the studies reported, the projectile target interaction time has been short, of the order of tens of microseconds.

One of the questions which has been discussed is therefore whether interface defeat also can be achieved for the much longer interaction time which prevails in a full scale tank application (hundreds of microseconds).

It can for instance be argued that there exists an upper limit for the time that interface defeat could prevail due to the specific damage mechanisms of ceramic materials. This would then mean that interface defeat could exist only for short times, not the long interaction times involved in the cases of long rod tank projectiles.

In this study, an experimental investigation was undertaken to find out whether interface defeat could prevail for substantially longer times than the tens of microseconds that have been reported earlier.

EXPERIMENTAL TECHNIQUE

The experiments were performed with a two-stage light-gas gun using the reverse impact technique. Confined silicon-carbide cylinders were launched at stationary long tungsten rods and the interaction process was monitored using flash X-rays.

Targets and projectiles

The geometry of the confined ceramic target is shown in Figs. 1 and 2. The ceramic cylinders, with nominal length 20 mm and diameter 20 mm were made from silicon carbide. The silicon carbide was produced using the pressure-assisted densification technique.

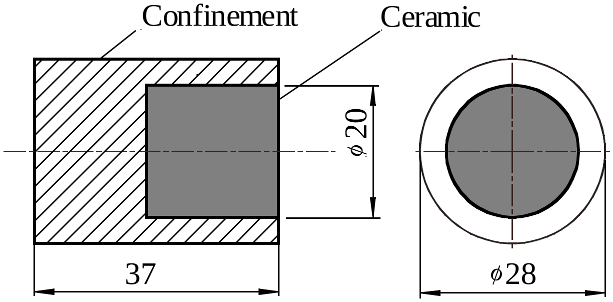

Figure 1: Main dimensions of the ceramic target (mm).

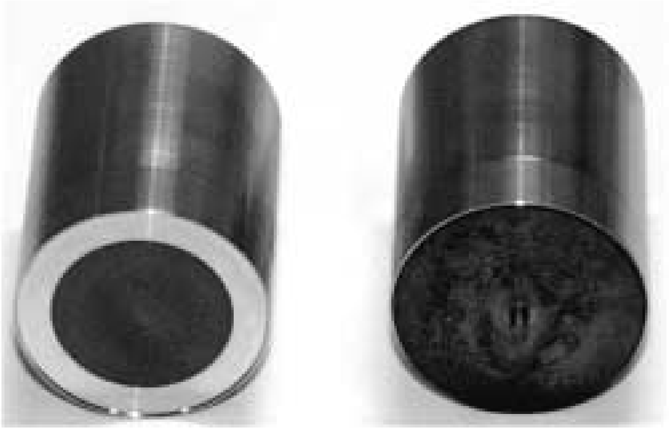

Figure 2: Ceramic target without (left) and with front lid (right).

The steel confinement was made of marageing steel (Mar 350, yield strength 2.6 GPa). The confinement was made in one part by boring and lathing a hole with diameter 0.07 mm smaller than that of the ceramic cylinder. The ceramic was then shrink-fitted into the confinement, and a lid was glued onto the front face of the ceramic.

The lid was designed in such a way that it would eliminate the initial impact shock, set up the interface defeat process and then be rapidly eroded to eliminate any further interaction with the projectile.

The projectiles were made from tungsten alloy (DX2M, density 17600 kg/m^3, yield stress 640 MPa) and had a diameter of 1 mm. In the first experiment, a 155.7 mm long projectile was used. In the two next experiments five such rods were silver-soldered together to form 778.5 mm long rods. To ensure that the longer rods remained straight, the end surfaces of the original rods were lathed flat and put into a special fixture when soldered. During the experiments the long projectiles were kept in position using a support consisting of six 10 mm thick walls (Divinycell H45, density 45 kg/m^3) set 140 mm apart.

Experimental set-up

The target was launched against the projectile, and four 450 kV flash X-rays were used to give pictures of the interaction process at four different times after impact. Two pairs of 150 kV flash X-rays were used to give pictures of the position of the target to enable evaluation of the velocity before and after the interaction. The position of the flash X-rays relative to the 779 mm projectiles can be seen in Fig. 3.

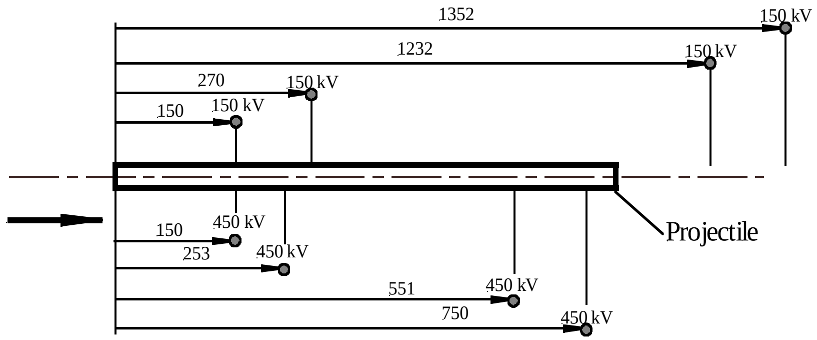

Figure 3: The position of the flash X-rays relative to the projectile in experiments 2 and 3. The target comes from the left.

The projectile was placed in the line of fire mounted in its Divinycell fixture. The alignment was achieved using a laser. The deviation in angle between the axis of the projectile and the line of fire was measured to be smaller than 0.05°. The flash X-rays were triggered by shortcutting 0.07 mm wires mounted on the tip of the projectile. Fig. 4 shows the projectile in its fixture in front of the gun barrel.

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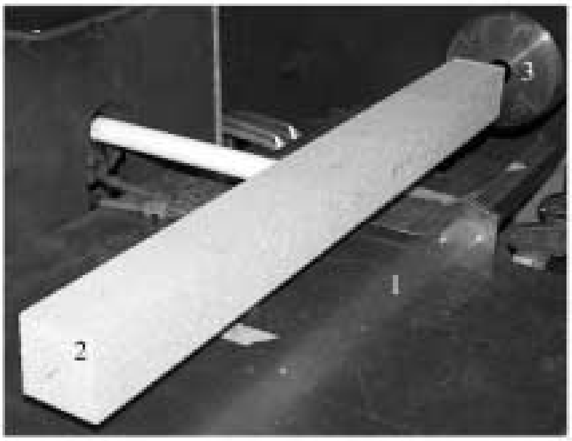


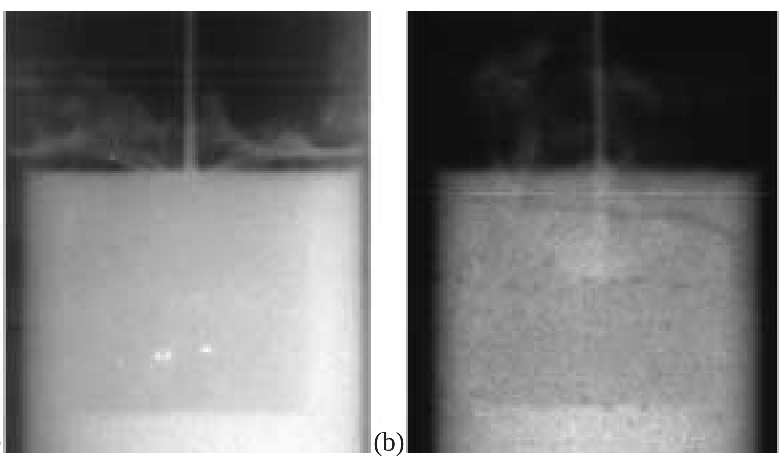
Figure 4: Experimental set-up: (1) film cassettes, (2) projectile fixture and (3) gun barrel.

Registrations and evaluation method

Three experiments were carried out with nominal impact velocity 1500 m/s. This velocity is of the order of 90% of the highest velocity for which interface defeat has been observed for this ceramic material [5].

The two first 150 kV X-ray pictures were taken at the beginning of the interaction process and the third and fourth after the interaction. These pictures gave the approximate impact velocity and the velocity after the projectile was completely consumed.

The four 450 kV flash X-ray pictures gave information on how the interaction between the ceramic and the projectile took place. The two pictures in Fig. 5 show projectile-target interaction at (a) interface defeat and (b) penetration.



(a) (b)

Figure 5: Flash X-ray registrations of typical projectile-target interaction behaviour. (a) Interface defeat (shot 2 at 132 μs after impact) and (b) penetration (shot 3 at 366 μs after impact).

The pictures were digitised and the penetration depth *P* and length of the projectile *L* were evaluated from the pictures at four different times in each experiment.

RESULTS

In Table 1, the velocity before and after the interaction are shown together with the penetration depth and projectile length at four different times after impact. In the diagram in Fig. 6, the penetration and the length of the projectile are plotted versus time after impact.

Tabele 1: Velocity before and after the interaction, penetration depth and projectile length.

Test nr.	Velocity $[ms^{-1}]$	Time after impact t [µs]	Penetration P [mm]	Length of projectile L [mm]
1 (285)	1490	0	0	155.7
	--	25.6	0	119
		50.9	0	83
		75.1	0	50
		99.6	0	15
2 (286)	1500	0	0	778.5
	1460	99.7	0	628
		132.3	0	580
		366.3	37	273.5
		-	-	-
3 (287)	1510	0	0	778.5
	1440	99.7	0	628
		171.3	0	519
		366.3	9	238
		499.3	$20 < P < 37$	$92 < L < 75$

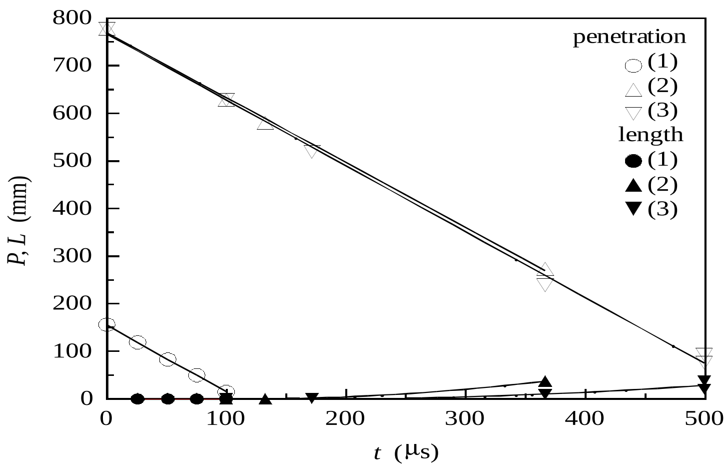


Figure 6: Penetration *P* and length of projectile *L* as a function of time after impact *t* for the three tests.

DISCUSSION

In all three experiments, a registration was made 100 µs after impact. Interface defeat without any penetration was obtained for each test at this time.

In test 1, with the 156 mm long projectile, most of the projectile was then eroded. In test 2, the projectile had just penetrated the whole target (20 mm ceramic plus 17 mm steel) when the third 450 kV X-ray was triggered at 366 µs after impact. In test 3 the projectile had penetrated 9 mm into the ceramic after 366 µs and perforated the ceramic but not the steel backing after 500 µs.

The time of interface defeat in the tests is obviously at least 100 µs for test 1, 132 µs in test 2 and 171 µs in test 3. Thus, the measured maximum time of interface defeat in these tests is 171 µs.

From the third exposure in test 3, an estimate of a maximal time of interface defeat is done using the fact that the projectile has penetrated 9 mm into the ceramic at this time. Assuming that the penetration velocity in the silicon carbide is constant and the same as observed in [6], u = 0.65 mm/µs at v_p = 1500 m/s (the penetration velocity is corrected for the different projectile densities, 19300 kg/m^3 in [6]). The time to penetrate 9 mm into the ceramic will then be 9/0.65 = 14 µs. This will give the upper time limit for interface defeat to be 366 – 14 = 351 µs.

With this penetration velocity, an estimate of the time to perforate the steel backing is 500 – 366 – 11/0.65 = 120 µs when it is assumed that the projectile is just to perforate the steel backing. This time to penetrate the steel backing is at least, with a factor of two, too large. Using Tate's model [7] with R_t = 11.7 GPa (4.5 times the yield stress = 2.6 GPa of marageing steel) gives the penetration time of the steel backing to be 17/0.35 = 50 µs.

Using this estimate of the time to penetrate the steel backing, a new estimate of the penetration velocity in the ceramic will be u = 11/(500 - 50 - 366) = 0.13 mm/µs. This gives the time of interface defeat to be 366 – 9/0.13 = 296 µs.

Test 3 thus shows that interface defeat has taken place, at least for 171 µs (measured), and that the reasonable estimate is between 300 µs and 350 µs.

In these experiments, the diameter of the projectile was 1 mm, which is substantially smaller than for tank gun projectiles. Whether the results presented here are relevant also for projectiles with larger diameter has not been investigated.

If it is assumed however, that it is absolute time that decides when the ceramic breaks down and penetration starts, then the times obtained here should be relevant for projectiles with larger diameter.

If the replica modelling law is assumed to be valid for ceramic targets (which is indicated by e.g. [8]), the conclusion would be that interface defeat should be possible for considerably longer times for larger calibres (milliseconds).

CONCLUSIONS

Interface defeat can be sustained in silicon carbide for hundreds of microseconds. It can thus be concluded that interface defeat could constitute a viable defeat mechanism also against full-scale high-density long rod projectiles.

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