Disturbance of Shaped Charge Jets by Bulging Armour

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Summary

Two flash X-ray pictures of the passing jet after a bulging armour are presented which give the disturbance effect to the jet – some earlier particulation time and iterative jet eruptions – but only after some time delay. The analysis of the jet velocities of the eruptions allows to calculate the time intervals or roughly the disturbance frequency of the used bulging armour arrangement.

1. Introduction

Bulging armour is an interesting and relatively often used protecting system which is typically not too much published. The patent of the author was filed 1973(1). The principle function is already described in detail in his overview paper on "Armour" 1993(2) on a number of interlayer materials, as the dependence on impact angles (Fig. 11 and Fig. 12 of Ref. 2). "Spall" armour – called in this earlier publication – is identical to "bulging" armour. Israeli authors presented a theoretical consideration to this topic in 1992(3) and again together with some experimental results in 1995(4). A very nice numerical parametric study was recently published by Rosenberg 1998(5).

Experimental results with a numerical support to this topic are given by Thoma et al.(6). This paper does not describe the used materials. The author assumes that it was not a totally passive system but also not a fully detonative explosive reactive armour system(7). It was maybe something between these two extremes, called in USA "Self-Limiting Explosive Reactive Armour" or "Non-Explosive Reactive Armour (NERA)".

In this present paper two tests are described with two "new" base inert materials – Dyneema(8) – between two metal plates.

2. Test Setup

A 115 mm shaped charge with a typical copper jet and 9.3 mm/µs tip velocity was horizontally installed in a stand-off of 350 mm to the front side of the special armour sandwich. The two inert sandwich arrangements consist of a 2 mm mild steel plate on the front or impact side, a 20 mm thick middle layer of Dyneema(8) and a 4 mm mild steel plate on the exit side in direct contact as good as possible without any adhesive to the carrying plate layer. Both had an areal density of 21 kg/m^2 and were built from the same Dyneema fibres. A UD Dyneema panel – uni-directional fibres – with a fiber content slightly over 80% was used for the first test. For the second test a panel of plain woven fabric with a fiber content of around 90% was taken. The sandwiches had 500 mm length and 250 mm width and were arranged under 60° NATO-angle to the shaped charge axis. The charge was lined up to the center of the sandwiches. In 1700 mm distance or roughly 15 caliber standoff to the shaped charge mild steel witness blocks were set to measure the residual penetration capability of the partially disturbed jets. A make-switch was arranged 100 mm in front of the mild steel blocks to trigger the flash X-rays for getting a picture of the passed jet. In the protecting cassette was one of the two installed 2 times 900 mm long X-ray films with intensifier screens (Figure 1). A picture of the test setup is shown in Figure 2 with the 115 mm shaped charge in front on the left side, followed by the sandwich in the middle and on the right side the make-switch with the mild steel witness blocks behind it. The long protecting cassette for the X-ray films is visible in the background.

Two flash X-ray exposures were used for the diagnostic of the shaped charge jets. The FXR tubes were arranged one over the other at the same distance of 350 mm. The FXR tube of the first flash X-ray was arranged exactly perpendicularly to the sandwich or exactly facing the surfaces where the second flash X-ray was lifted up and was looking obliquely and slightly from top to the sandwich. The first flash X-ray exposure was made with a given time delay of 101 µs. The delay generator was triggered by an ionization probe in 10 mm distance from the base of the 115 mm shaped charge's liner. The second flash X-ray was triggered by shortening the make-switch by the jet tip in 1600 mm standoff.

3. Test Results

The two achieved flash X-ray exposures with their velocity bars are presented in Figure 3. Their original jet tip velocity of 9.3 mm/µs is eroded a little down to a residual jet tip velocity of around 9.0 mm/µs by the perforation of the sandwich under 60° NATO-angle. The jet tip section is

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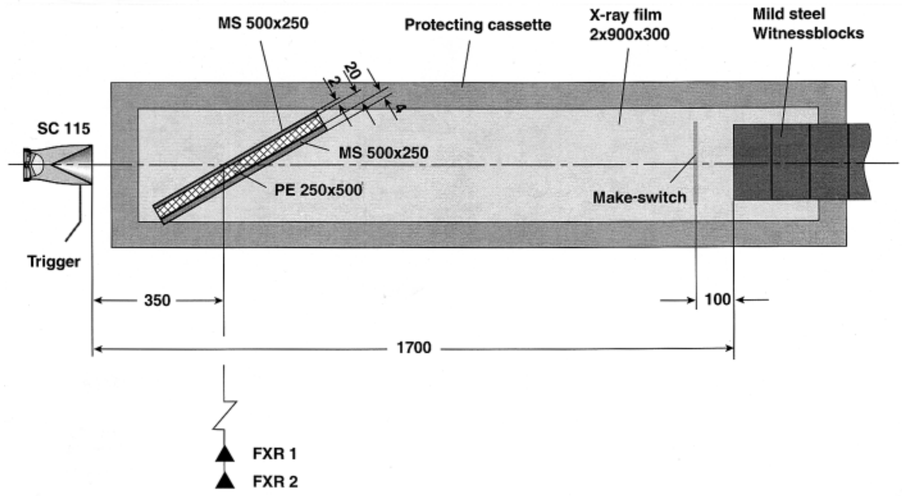

Figure 1. Test setup of bulging armour against 115 mm shaped charge in front of double flash X-ray diagnostic; all distances in mm.

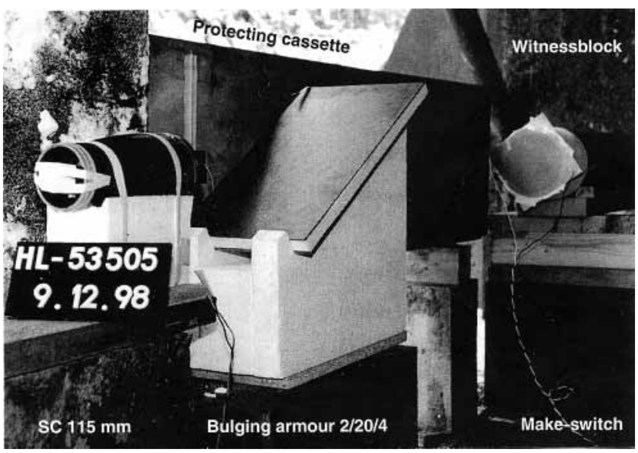

Figure 2. Picture of the test setup with the shaped charge in front of a bulging armour 2/20/4 of mild steel plates on 20 mm Dyneema under 60°, the make-switch on the right side with the witness blocks for measuring of residual penetration. In the background the protecting cassette for the 1.8 m long FXR films.

slightly bent at the shaped charge firing SC 53505 (Figure 3, top) but not at the shaped charge firing SC 53506. In Figure 3, the jets look nearly not disturbed on the first exposures after around 101 μs.

The second flash X-ray exposures after the delay times of 172 μs, respectively 175 μs show that the jets from residual tip velocity of around 9 mm/μs to 6.3 mm/μs look not at all disturbed. Then the jets seem to be necked or to be particulated earlier as usual, and from 5.3 mm/μs on down the jets are multiply disturbed by the bulging armour.

The tip of the jet creates an elliptical hole in the target or in the sandwich plates and the edge of the hole needs some time before the bulging plates are touching the passing jet the first time and are creating the first deviation. By the interaction of the bulging plate with the jet, the plate is now a little more eroded or more consumed and the plate has to move again some distance that the edge of the slit in the plate interferes a second time with the passing jet. This process is iteratively continuing and gives the multiple eruptions along the jet.

By the iterative interaction of the bulging plates with the jet not only elliptical holes are created but more or less a slit is

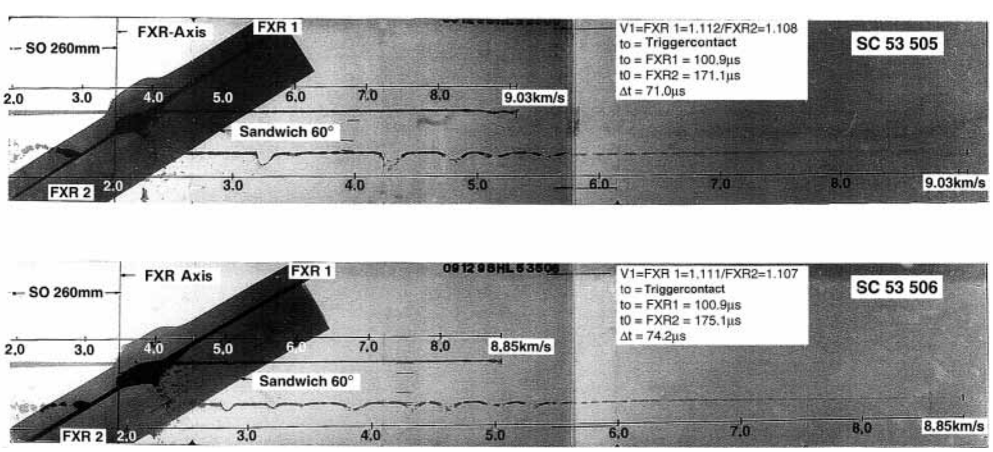

Figure 3. Flash X-ray pictures of two firings against bulging armour 2/20/4 under 60° after 100 μs time difference to the detonation of the shaped charge and around 170 μs.

made in the plates, especially in the rear plate. Figure 4 shows the sandwich targets with the 2 mm front plates on the left side and the 4 mm mild steel plates on the right side which have the typically long slits.

The residual penetrations were 590 mm and 610 mm in the stack of mild steel witness blocks corresponding to a jet velocity difference of 3 mm/μs which means from 9 mm/μs down to roughly 6 mm/μs. The penetration P of a particulated jet is given by the Eq. (1)[9] with

$$P = (v_{jR} - v_{j\,\min}) \cdot t_p \cdot \sqrt{\rho_{jet}/\rho_{target}} \qquad (1)$$

where v_{jR} is the residual jet tip velocity, $v_{j\,\min}$ the so-called cutoff velocity, t_p the particulation time of the jet, and ρ_{jet} and ρ_{target} are the densities.

For $\Delta v_j = 3$ mm/μs and a particulation time t_p of 200 μs a copper jet gives around 600 mm = (9 mm/μs − 6 mm/μs) · 200 μs · $\sqrt{8.9/7.85}$) penetration.

The typical cutoff velocity for this shaped charge type in mild steel blocks in the standoff of 12 caliber is in the range of 4 mm/μs[10]. Therefore, this special target reduced the penetration around 400 mm under the given material and geometric conditions.

4. Analysis

The flash X-ray pictures can be analyzed with regard to their jet velocities where some disturbances start. The jet tip arrived with its residual maximum velocity at the exit side of the sandwich after 44 μs ((350 mm + 50 mm)/9 mm/μs). The first interaction of the bulging plate with the jet is visible at 5.3 mm/μs jet velocity. This jet section passed the exit side of the target after 76 μs (400 mm/5.3 mm/μs). This gives a time difference of 32 μs (76 μs − 44 μs). The "activating time" for this target against this type of shaped charge jet, distance and used angle is therefore around 32 μs, which is a relatively long time interval.

From the further disturbances with their corresponding jet velocities can be calculated again the passing times from the exit side of the target. The time differences thus obtained give the repetition times where the bulging steel plate is touching again and again the shaped charge jet. For the two firings these values are summarized in Table 1.

The analysed Δt-values are presented in Figure 5 as a function of jet velocity, which shows frequencies of 200 kHz in the faster velocity range and about 50 kHz in the slower jet velocities range beneath 4 mm/μs.

The disturbances, respectively eruptions of the elongating jet in the second flash X-ray exposure after around 170 μs can be found as notches in the jet at the first flash X-ray exposure after 100 μs but without any eruptions (Figures 6 and 7). The introduced transverse velocities of 0.1 mm/μs to 0.2 mm/μs are not well visible in the short time differences of 20 μs at maximum or less after the interaction with the bulging plate.

The flash X-ray pictures of Figure 3 are digitized and the earlier exposures – after around 100 μs – are 1.7 times magnified and therefore 1.7 times stretched, so the disturbances can be much better and directly compared to each other (Figures 6 and 7). The notches in the earlier or in the first FXR-exposure or with the shorter time differences can be found as corresponding eruptions in the later or in the second FXR-exposure with larger time differences to the interaction times. The velocity bars are drawn from the base

Table 1. Analysed Jet Disturbances

SC-Firing [No]	v_{jet} [mm/μs]	Bulge of jet	Marks on figures	t [μs]	Δt [μs]
53 505	5.678	small	a	70.4	
	5.233	small	÷	76.4	6.0
	4.683	medium	b	85.4	9.0
	4.421	large	c	90.5	5.1
	3.346	large	÷	119.5	29.0
53 506	5.446	small	a	73.4	
	5.086	very small	÷	78.6	5.2
	4.777	medium	b	83.7	5.1
	4.443	small	c	90.0	6.3
	4.005	medium	÷	99.9	9.9
	3.285	medium	÷	121.7	21.8
	2.940	medium	÷	136.0	14.3

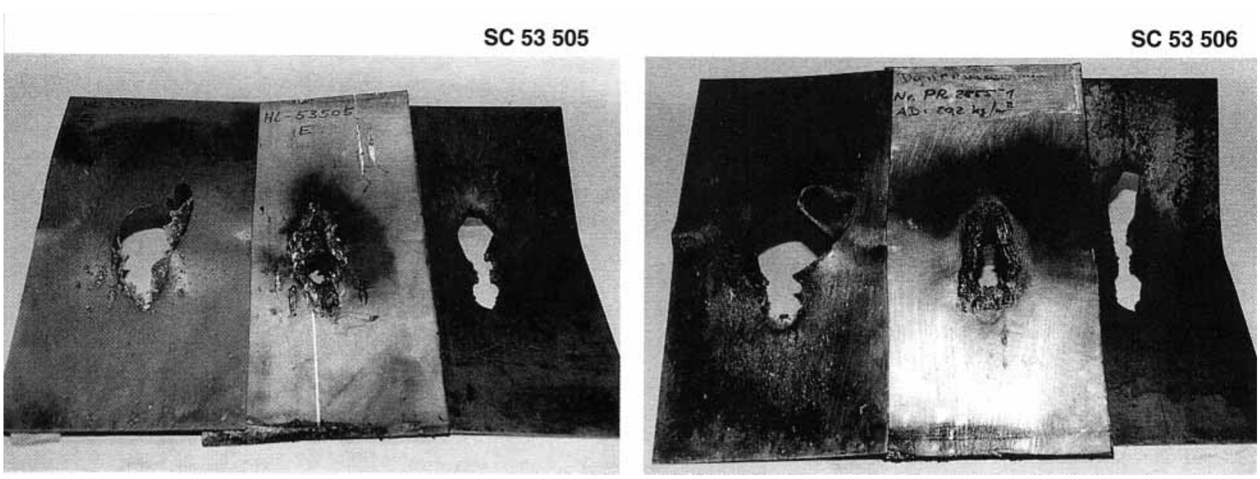

Figure 4. Slits and craters in the 2 mm mild steel plate on the left side, the 20 mm Dyneema plate in the middle and the slit in the 4 mm mild steel plate on the right side.

of the shaped charge and the time is calculated by the shortening of the make-switch through the detonation wave 10 mm above the base, which gives not exactly the virtual original conditions. But the values are not far away and this fact explains the small differences from the marked points *a* to *c* to the velocity lines in both exposures of one firing.

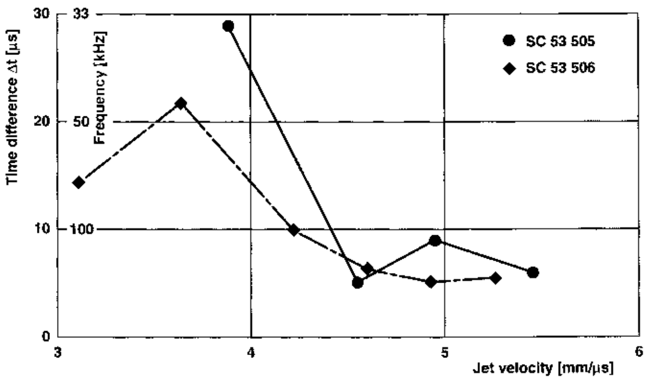

Figure 5. Time differences Δt of the disturbances of the passing jet as a function of the jet velocity.

The maximum amplitudes of the eruption are around 20 mm at jet velocities of around 4.0 mm/μs. This gives a time difference of roughly 100 μs with the interference to the bulging plate. This means about 0.2 mm/μs transverse velocities to the amplitude maxima of the disturbed jet section.

Another effect is happening on this jet by this special target. This jet typically is not particularized in the velocity range of 6.0 mm/μs after around 170 μs time. This earlier particulation time has to come from this type of target which leads the jet to particulate a little earlier, for SC 53505 roughly from 7.0 mm/μs and for SC 53506 from 6.3 mm/μs on. This can only be found and seen if reference tests are available which is the case to the author for this type of shaped charge.

5. Conclusion

The mechanism of a bulging armour to a shaped charge jet can be seen on flash X-ray pictures of the passed section of a shaped charge jet. The elliptical holes built in soft iron plates are remarkably large, so that the jet with the residual tip

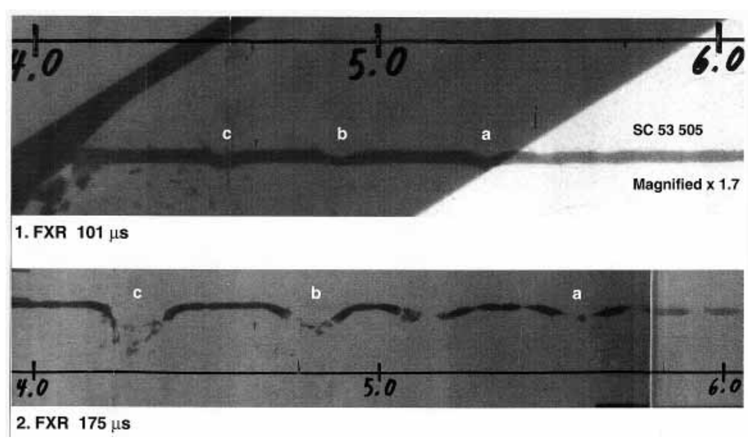

Figure 6. Comparison of the disturbances of the jet on the flash X-ray exposures after 101 μs and 175 μs which means shorter time after the interference with the bulging plate and later times of firings SC 53505. The earlier picture is 1.7 times magnified to the later picture for better comparison.

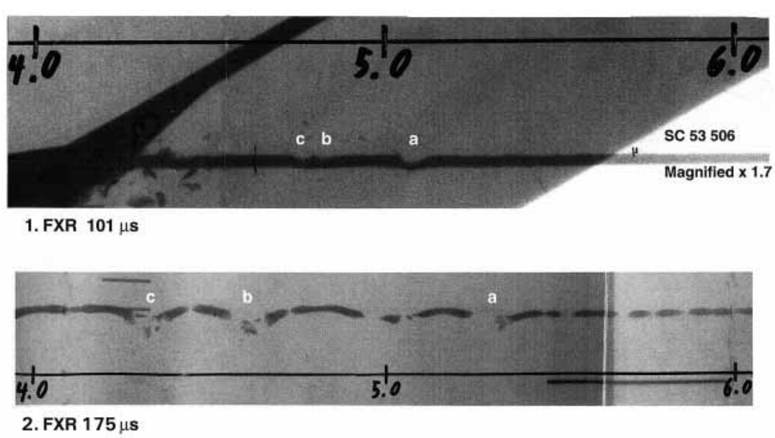

Figure 7. Same comparison for the second firing SC 53506.

velocity of 9.0 mm/µs down to roughly 6 mm/µs is not especially disturbed.

Remarkable is the earlier break-up time of the jet from the velocity of about 7.0 mm/µs to 6.5 mm/µs on. The frequency of the disturbed jet by the iterative interaction with the bulging plate is around 50 kHz to 200 kHz.

The direct comparison of the two flash X-ray exposures of the earlier to the later time is a little surprising because the jet looks much less influenced or disturbed after the short time differences compared to the second exposure with a little larger time differences.

6. References

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