REVERSE SPACED TARGET EFFECT AT SHAPED CHARGE FIRINGS AGAINST RHA TARGETS

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At firings with shaped charges against targets consisting of some spaced steel plates and a semi-infinite witness block behind them normally the total penetration depth of the shaped charge jet into such spaced targets is smaller than that into single semi-infinite steel blocks. This effect can be called “spaced target effect”. At experiments performed during the last two years a reverse effect could be observed: Under some circumstances the total penetration depth into spaced targets can be greater than that into semi-infinite targets. This paper gives a report on the experiments mentioned above and the so called “reverse spaced target effect”. The experiments described here were performed using a medium caliber shaped charge and a small caliber shaped charge. The existence of a “reverse spaced target effect” became evident at firings with both charges against single plate targets made of RHA steel. Attempts for a phenomenological explanation of the effect are given by considering the effects due to steel hardness and charge precision when a shaped charge jet penetrates either a semi-infinite or a spaced target.

INTRODUCTION

In the framework of vulnerability studies a lot of shaped charge firings against single- and multi plate targets were performed at the Ernst-Mach-Institute (EMI) in the near past. Plate number, plate thickness and gap size between plates were varied. For instance, the distances between neighbouring plates and last plate and witness of the spaced targets were varied from less than one third of a charge caliber to more than seven charge calibers. Usually plates and witness of the targets consisted of the comparatively soft C 60 steel. At all experiments with this target material a more or less strong spaced target effect was observed, i.e. the total penetration depth into the spaced target was smaller than the penetration depth into a semi-infinite target made of C 60 steel at the same standoff distance. The practical meaning of the well known normal spaced target effect is that structures like armoured vehicles can get some protection against shaped charge threats by placing a steel plate in front of the main armor.

At some of the tested single plate targets C 60 steel was replaced by harder RHA steel, both at the single plate and the semi-infinite witness. Due to this change of target material the size of the spaced target effect became smaller in case of targets with a relatively small total spacing between plate and witness and even reversed in case of targets with a larger spacing. In the latter case the total penetration depth into the spaced target became greater than that into a semi-infinite RHA target.

EXPERIMENTS

Shaped charges

Experiments were performed with a medium caliber shaped charge SC 1 (Russian shoulder weapon munition with caliber of about 70 mm) and a small caliber shaped charge SC 2 (bomblet munition with caliber of about 45 mm). Both charges are equipped with 60^o copper liners and produce shaped charge jets with tip velocities of 8.1 km/s. The liner of the SC 1 has got a caliber of 64 mm and a wall thickness of 1.5 mm. The corresponding values of the SC 2 liner are 42 mm and 1.0 mm, respectively. The reference penetration depths into semi-infinite C 60 steel at a standoff of 2 calibers are about 360 mm in case of the SC 1 and 240 mm in case of the SC 2. More details on SC1 and SC2 are given in [1].

Figures 1 and 2 show flash x-ray photographs of the jets of the two shaped charges. The jet of SC1 was photographed at 50 µs, 90 µs, 115 µs and 160 µs after charge ignition and the jet of SC2 at 100 µs, 135 µs, 200 µs and 300 µs after charge ignition.

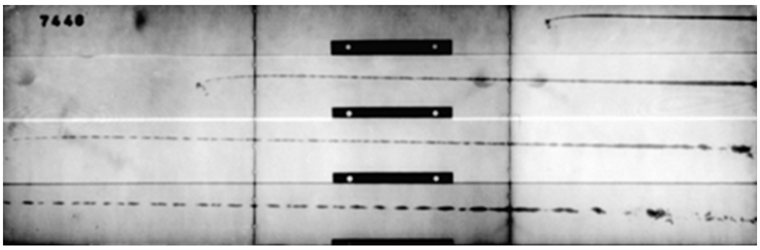

Figure 1. Four channel flash x-ray photograph of the jet of SC 1

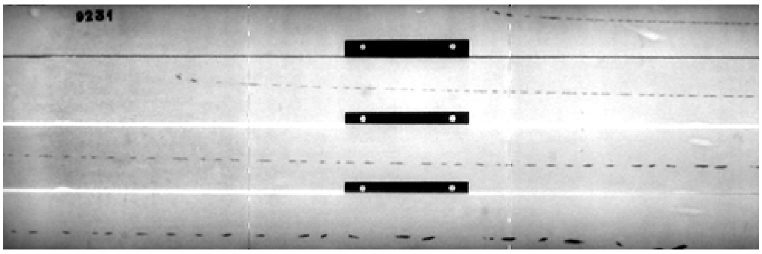

Figure 2. Four channel flash x-ray photograph of the jet of SC 2

Because breakup times of SC1 and SC2 are about 110 µs and 75 µs, respectively channels 3 and 4 of figure 1 and all channels of figure 2 show jets that already have been particulated. The single particles of SC 1 don't have the ideal elliptic form which is evident for a high copper quality of the liner and some particles of SC 2 at the rear part of the jet are tumbling. Both jets exhibit some bending in their tip region. These circumstances and the shapes of their standoff curves (see figures xy to xy) indicate that the two shaped charges are no highest precision charges. The maximum penetration depths of both shaped charges into C 60 steel and RHA are smaller than 6 calibers. After their maximum both standoff curves rapidly decrease, the RHA curves lying below the C 60 curves and showing a steeper drop than the C 60 curves.

Test-Set-ups

The depth of penetration tests were carried out by firings against targets consisting of one to four plates with thicknesses in the range of 20 mm to 180 mm and a semi-infinite steel witness block. Steel plates and witness block of each target were made of the same material, either C 60 steel (Vickers hardness number HV100 = 200-230) or RHA-L steel (Vickers hardness number HV100 = 280 – 300). Targets with similar structure were combined in test series denoted with capital letters. From the many tested targets only a few test series will be discussed in the following, especially those showing a reverse spaced target effect. More targets are treated in [2].

The targets shown in figure 3 (test series A with targets A1 – A4) consisted of 1 to 4 plates made of C 60 steel with different plate thicknesses at each target and a semi-infinite witness block made of C 60 steel too. All test set-ups of series A - tested with SC 1 only - had the same distance between the shaped charge and the first plate (146 mm) and between the last plate and the witness (50 mm). The sum of plate thicknesses constantly was equal to 120 mm and the sum of gaps between the plates constantly was

60 mm (excepted the single plate target A1) so that with increasing plate number the gap width between two neighbouring plates was decreasing.

Figures 4-5 show single plate targets against which firings with both shaped charges were done. In case of series D, G (firings with SC 1), I and J (firings with SC 2) C 60-steel was used as target material. In case of test series L (firings with SC 1) and O (firings with SC 2) having the same structure like series D and I RHA steel was used as target material.

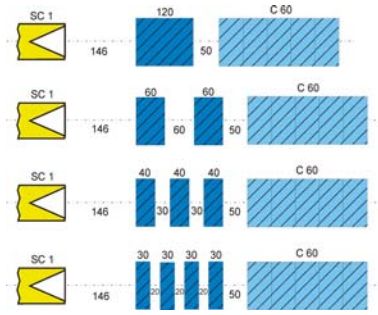

Figure 3. Targets of test series A (SC1)

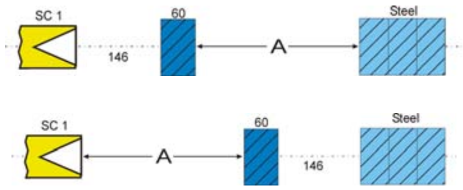

Figure 4. Single plate targets tested with SC1
Top: Targets of test series D (C 60), L (RHA)
Bottom: Targets of test series G (C 60)

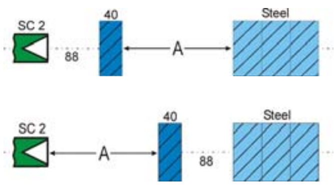

Figure 5. Single plate targets tested with SC2
Top: Targets of test series I (C 60), O (RHA)
Bottom: Targets of test series J (C 60)

In case of the test set-ups for SC1 the characteristic distance A between plate and witness or shaped charge and plate took the values 170 mm, 290 mm, 410 mm, 530 mm and 650 mm. In case of the test set-ups for the smaller SC2 the distance A took the values 113 mm, 193 mm, 193 mm, 273 mm and 353 mm.

Experimental results

At all shaped charge firings – with SC 1 and SC 2 – against targets made of C 60 steel the normal spaced target effect was observed. So it was in case of the multi plate targets of test series A and the single plate targets of test series D, G, I and J. At other target configurations not shown in this paper but for instance in [2] the finding was the same.

The penetration depths of test series A containing multi plate targets with rather narrow gaps between all its components are shown in figure 6 together with the reference penetration value (Ref.) of SC1 into C 60 steel at 2 calibers standoff. All penetration depth values are located in the region from 250 mm to 280 mm lying 110 mm to 80 mm below the reference penetration. So the spaced target effect can be estimated at about 25% to 30%.

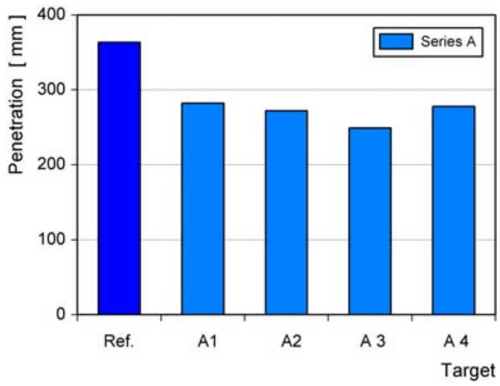

Figure 6. Penetration depths of test series A

Figures 7 shows the penetration results of firings with shaped charge SC 1 against the C 60 steel targets of test series D and G and the penetration results of firings with the smaller shaped charge SC 2 against the C 60 steel targets of test series I and J. In addition to the spaced target penetration curves the diagrams contain the appropriate standoff curves.

To be able to compare the penetration depths into spaced targets with those into semi-infinite targets, i.e. the standoff curves in both cases the total penetration depth is drawn as a function of the so called “free distance”. The free distance of a spaced target is defined as the sum of all air gap lengths between shaped charge and witness. At the targets under consideration it is equal to the standoff distance plus the distance A. The total penetration depth is given by the sum of thicknesses of penetrated plates and the residual penetration depth into the witness.

Looking at figure 7 it can be seen that the penetration depth values of the spaced targets are located far below the standoff curves. This is due to the normal spaced target effect. In case of SC 1 and test series D and G it ranges from about 20% to more than 60% depending on the value of the free distance. In case of SC 2 and test series I and J the spaced target effect ranges from about 5% to 40%.

The origin of the spaced target effect may be explained by the assumption that the focussing of shaped charge jet particles by a continuous crater hole is interrupted by the air gaps of spaced targets. While flying through these air gaps jet particles can deviate from the main axis of penetration because of their inherent lateral velocity which is directed perpendicular to the main axis of penetration. Particles deviating too far from this axis can’t contribute to the depth of the crater hole in the witness. They only lead to a widening of the impact crater.

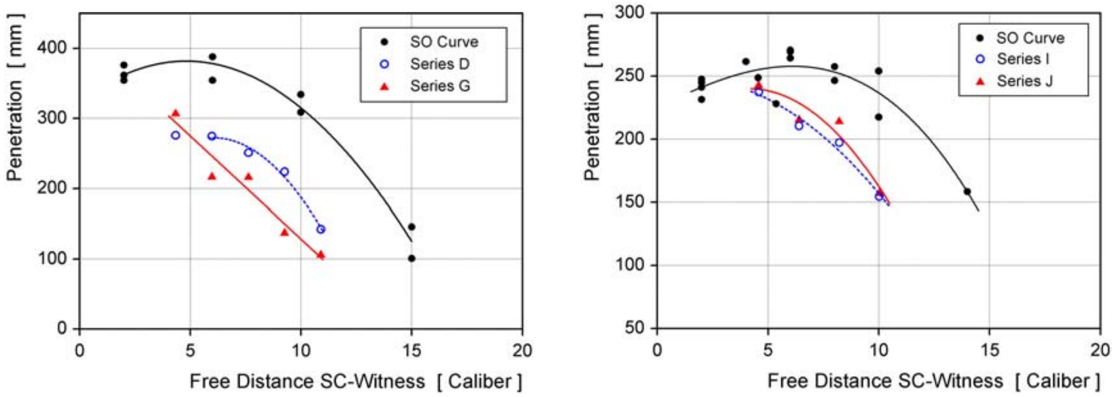

Figure 7. Left: Penetration of SC 1 into a semi-infinite C 60 target (SO-Curve) and into the spaced targets of series D und G made of C 60 steel.
Right: Penetration of SC 2 into a semi-infinite C 60 target (SO-Curve) and into the spaced targets of series I und J made of C 60 steel.

Figures 8 shows the penetration curves for test series L (SC1) and O (SC2) where the targets had the same structure as at test series D and G, respectively but C 60 steel was replaced by the harder RHA steel.

Now the locations of the spaced target penetration curves relative to the standoff curves drastically change in comparison to the corresponding C 60 curves. At both test series L and O the penetration values of the spaced targets are no longer continuously located below the standoff curves. Instead the penetration values of the spaced targets are located on rather straight lines that intercept the standoff curves at values of free distance of about 8 calibers. Above this distance the penetration depths into spaced targets are greater than the corresponding standoff penetration depths. This is the effect which is called "reverse spaced target effect" in this paper.

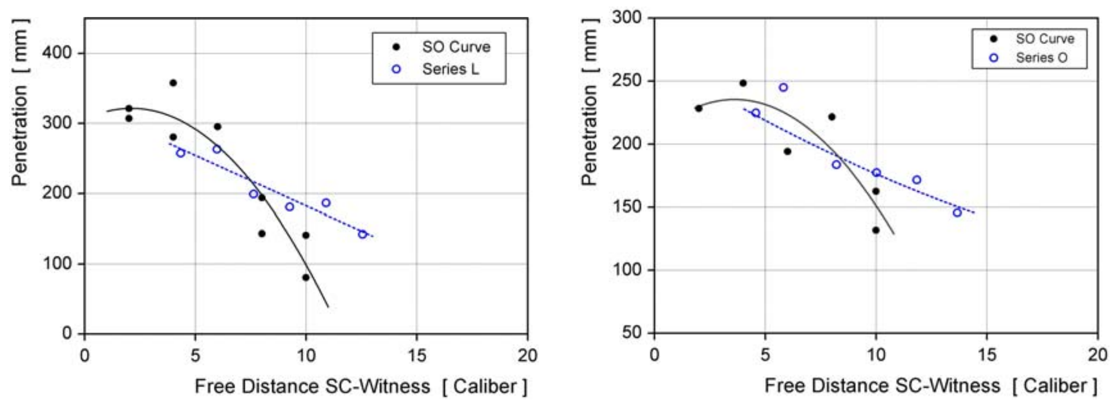

Figure 8. Left: Penetration of SC 1 into a semi-infinite RHA target (SO-Curve) and into the spaced targets of series L made of RHA steel.
Right: Penetration of SC 2 into a semi-infinite RHA target (SO-Curve) and into the spaced targets of series O made of RHA steel.

The starting-point of a phenomenological explanation of this effect is given by the observation that when going from C 60 steel to RHA steel the standoff curves show a stronger decrease than the penetration curves of the spaced targets at free distances above about 8 calibers. This behaviour may be caused by the following partly competitive effects: 1. Crater hole diameters at RHA targets are smaller than at C 60 targets thus causing smaller penetration depths. 2. Gaps within spaced targets allow jet particles to deviate from the axis of shot. This is the normal spaced target effect decreasing penetration depths. 3. Crater holes in the plates of spaced targets can have a focussing effect on the jet caused by particle deflections from their walls. This effect tends to increase penetration depths. Because of the smaller crater hole diameters at RHA steel here the focussing effect should be greater than at C 60 steel. 4. By spacing a target crater depths at witnesses are decreased so that it becomes easier for jet particles to reach the crater bottom.

At free distance values where the effects causing an increase of penetration depth exceed those causing a decrease a reverse spaced target effect can be found. Maybe by combining all mentioned effects by means of analytical or numerical theoretical methods a satisfying model can be developed. Because transverse jet particle velocities seem to play an important role for the existence of the reverse spaced target effect the shaped charge precision must be involved in the model. Maybe the effect can't be found at all when firing with high precision shaped charges.

SUMMARY

Shaped charge firings with a small and a medium caliber shaped charge against spaced plate targets made of C 60 steel or RHA steel have shown besides the normal spaced target effect a reverse spaced target effect. At all shaped charge firings against various single and multi plate targets made of C 60 steel the normal spaced target effect was observed. In case of some single plate targets made of RHA steel at free distances greater than about 8 calibers the reverse spaced target effect took place. The existence of this effect could be shown with both shaped charges having been used. For a theoretical explanation of the effect it is necessary to consider various partly competitive effects concerning the penetration behaviour of shaped charge jets into semi-infinite and spaced targets made of soft or hard steel. Probably charge precision, i.e. the degree of particle velocity components perpendicular to the ideal axis of shot must be involved in a theoretical model.

Further work could be to prove the existence or absence of the reverse spaced target effect at multi plate spaced targets and targets with oblique plates.

REFERENCES

[1] A. Holzwarth, Scaling of shaped charges and explosive reactive armor, *21st International Symposium on Ballistics*, (2004)

[2] K. Weber, A. Holzwarth, H. Dorsch, Experimental investigations for calibration of KE rod and SC jet penetration algorithms against plate targets, 2nd *European Workshop on Survivability, Noordwijkerhout, The Netherlands,* (2004)