19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

COMBINATION OF INERT AND ENERGETIC MATERIALS IN REACTIVE ARMOR AGAINST SHAPED CHARGE JETS

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For the protection of fighting vehicles against shaped charge threats their basic armor can be reinforced by additional sandwiches of metal plates with inert or energetic interlayers. The best protection is achieved by using explosives as interlayer, but because of psychological reasons and safety considerations an inert interlayer may be preferred. The disadvantage of inert interlayers is a less effective protection capability. This paper shows how to find a compromise. Sandwiches with interlayers consisting of rubber, mixtures of the energetic binder GAP and combinations of these materials with small amounts of high explosive were investigated. Flash X-ray pictures show the interaction between a medium caliber shaped charge jet and sandwiches with different kinds of interlayers as well as the disturbance of the jet behind these sandwiches which correlates with the penetration of the jet into the armor behind the sandwich.

INTRODUCTION

This paper describes our search for less sensitive materials for add-on armors of light combat vehicles against shaped charge threats. The protection power of unique sandwich systems consisting of steel flyer plates and inert interlayers like rubber against shaped charge jets is rather small. A more effective sandwich armor is explosive reactive armor (ERA), in which the interlayer consists of an explosive thus giving rise to danger for the crew of the combat vehicle and the surrounding of the vehicle due to the flying plates and blast, which can be vented upwards. To avoid the disadvantages of the two mentioned types of sandwich armors, we were looking for an interlayer material which is more effective than an inert substance and less sensitive than a pure high explosive. In the following we will refer to this kind of armor as reactive armor (RA). The basic material of our investigations was the energetic binder glycidyl azide polymer (GAP). The physical and chemical properties of GAP reported in personal communication [1] and literature [2], [3] made it a hopeful candidate for our purpose. Various mixtures of GAP and other materials have been tested. It turned out that, for the use as interlayer material in reactive armor sandwiches, it is necessary that there is some content of a high energetic material like RDX in the mixture in order to get an armor with a sufficiently high protection power.

EXPERIMENTAL SET UP AND SHAPED CHARGE

The experimental set up for testing the protection capability of reactive armor sandwiches with various kinds of interlayer materials is shown in figure 1. For the tests medium caliber shaped charges were fired against inclined sandwiches which consisted of two 2 mm thick mild steel flyer plates and an intermediate 8 to 12 mm thick layer of the material or combination of materials to be tested. The sandwiches had a lateral size of 200 mm × 50 mm. The firings were done at a standoff distance of 2 calibers and the angle of inclination of the sandwich targets was 60 degrees.

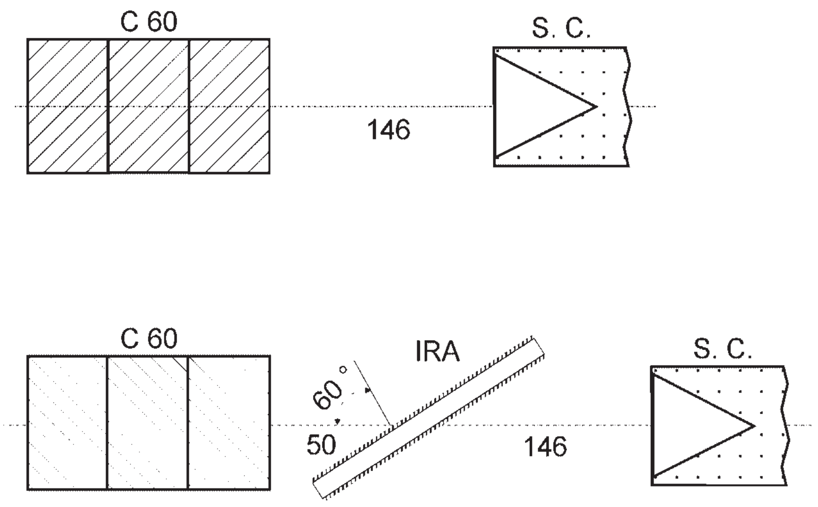

Figure 1: Experimental set up.

The protection performance of the targets was evaluated by measuring the residual penetration of the shaped charge jet into a witness of C 60 steel (hardness 230 HV 10) placed 50 mm behind the target. In addition, the penetrating jet was photographed by means of a four channel flash-X-ray equipment with an output power of 450 kV. Thus the disturbance of the jet behind the sandwich and the interaction between the jet and the flyer plates of the sandwich could be visualized.

The 73 mm shaped charge employs a conical copper liner with a 60° apex angle and an apex diameter of 64 mm. Its wall thickness is 1.5 mm. The tip velocity of the shaped charge jet was 8.1 km/s and its reference penetration depth into C 60 steel at a standoff of 2 calibers was measured to be 362 mm.

Tested Interlayer Compositions

As already mentioned above the test vehicles of our search for an effective reactive armor material were sandwiches of the type 2 mm steel / X / 2 mm steel, X being the interlayer to be tested. When such a sandwich structure is hit by a shaped charge jet the steel plates, often called flyer plates, are forced to move across the path of the jet thus disturbing it. In case of an inert interlayer the plate motion is caused by the elastic pressure transferred into the interlayer by the jet. Then the plate motion is only a bulging of the plates. If the interlayer is a high energetic material the plates are driven apart by a detonation and they are forced really to fly. In case of a less energetic interlayer both bulging and flying of the sandwich plates, the latter caused by a chemical reaction with an accompanying gas production, may become important for the distortion of shaped charge jets.

The tested mixtures of GAP are included in the list below.

- GAP = Glycidyl azide polymer + Desmodur N 100
- GAP + $CaCO_3$
- GAP + GZT (GZT = Guanidinazotetrazolat)
- GAP + 20% RDX
- GAP + 70% RDX

All of these mixtures were prepared by the Fraunhofer-Institut für Chemische Technologie (ICT), Pfinztal, Germany.

Because pure GAP is a liquid with an oily consistency for our purpose it was hardened with the hardening agent Desmodur N 100. In the following GAP + Desmodur is simply called GAP. Its density was ρ=1.27 g/cm^3. The densities of the other mixtures were ρ=1.03 g/cm^3 (GAP + $CaCO_3$ and GAP + 20% RDX) and ρ=0.97 g/cm^3 (GAP + GZT and GAP + 70% RDX). All mixtures had the consistency of soft rubber and could be cut with a sharp knife. The thickness of the interlayers built of these mixtures was 10 mm.

Furthermore experiments with combined interlayers of an 8 mm thick rubber or 10 mm thick GAP layer and an additional 1–2 mm thick layer of the high explosive Dottikon were carried out. Dottikon is a composition of 85% PETN and 15% binder. Its density is 1.4 g/cm^3 and its detonation velocity is about 7000 m/s. At the experiments with two intermediate layers the Dottikon layer was directed towards the shaped charge.

At our very first experiments sandwiches with 8 mm thick rubber interlayers (Perbunan, density ρ=1.45 g/cm^3) were tested. These sandwiches with a fully inert interlayer served as a standard target for the evaluation of the later tested sandwich armors.

EXPERIMENTAL RESULTS

The two channel flash X-ray photographs of Figure 2 show the interaction of a shaped charge jet with armor sandwiches containing interlayers of a very low density foam (thickness 10 mm), rubber and GAP, respectively. Each photograph was taken 100 µs and 120 µs after charge ignition.

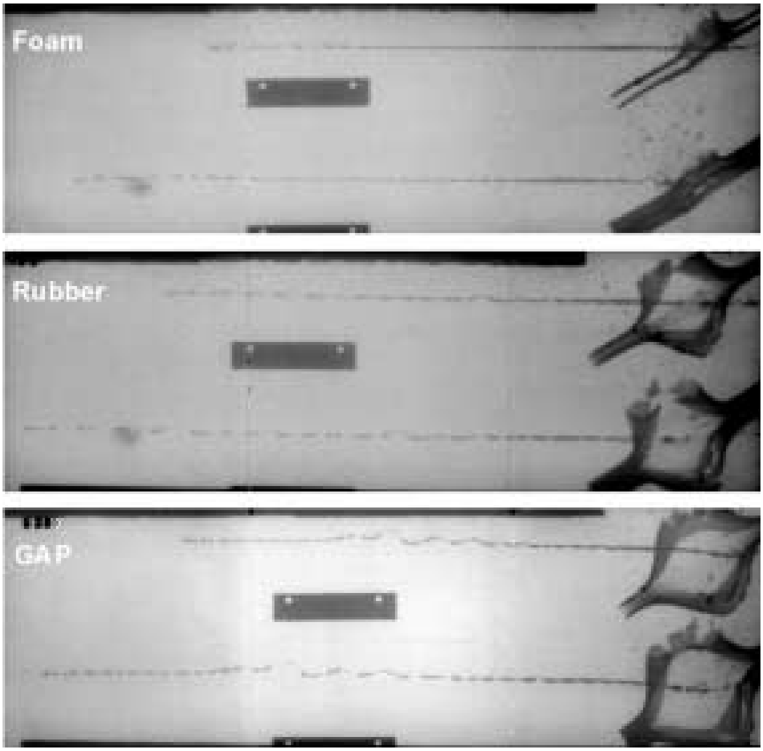

Figure 2: Interaction of a shaped charge jet with sandwiches containing foam-, rubber- and GAP interlayers.

The foam sandwich is penetrated by the jet without any bulging of the flyer plates and with almost no distortion of the jet behind them. However, the jet tip velocity is reduced from 8100 m/s in front of the target to 6200 m/s behind the target. This is due to material erosion at the jet at the beginning of the penetration process. In cases of rubber and GAP a strong bulging of the flyer plates can be observed. However, the jet disturbance caused by the bulging is very small at rubber as well as at GAP. The energetic Material GAP responds in the same manner to jet impact like the inert material rubber. This means that a shaped charge jet cannot ignite GAP or that an reaction immediately stops after ignition.

Figure 3 shows for the above mentioned sandwich systems the total penetration depth P_m of the shaped charge jet into the overall target, consisting of the sandwich and the steel witness behind it, versus the interlayer material. P_m can be called steel mass equivalent penetration depth, because for the determination of P_m the thickness of each perforated target layer was converted into the thickness of a steel layer with the same areal density. The left bar of figure three corresponds to the reference penetration of the used shaped charge into a semi-infinite steel target. The other P_m values of figure 3 reflect the degree of jet distortion that can be observed in Figure 2. By the sandwich with the foam interlayer the penetration depth is reduced by only 11% with respect to the reference value. With

GAP there is reached the same protection capability as with rubber. In both cases the reduction of penetration depth compared to the reference value is about 22%. The reference penetration depth $P_{m, Ref.}$ divided by P_m gives the so called mass effectiveness factor E_m which is a direct measure of the protection capability of a reactive armor. For reactive armors with sandwiches containing rubber or GAP interlayers we got an Em-value of 1.29. This value is much smaller than that of a typical explosive reactive armor, being in the range of 5 to 10.

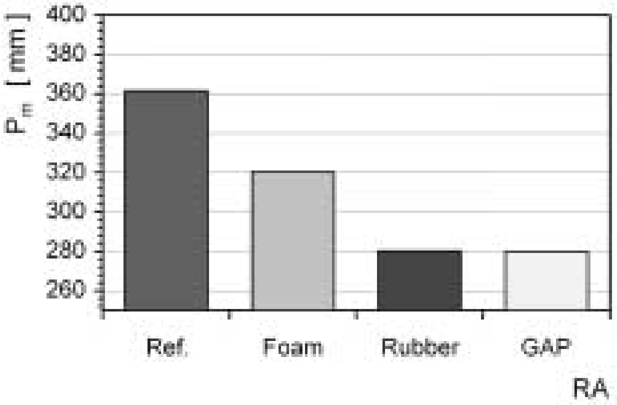

Figure 3: Penetration depth P_m versus various interlayer materials.

Because of the insufficient protection power attained with simple GAP + Desmodur next we tested mixtures of GAP with $CaCO_3$ and GAP with GZT. In the former mixture the reactivity should be enhanced by the generation of air bubbles within the mixture and in the latter one by adding a second energetic material. It was not much a success as it can be seen from Figure 4 where the result of this and the following experiments are summarized. With respect to rubber or GAP the total penetration depth P_m is reduced by only 8.5 % in both cases, GAP + $CaCO_3$ and GAP + GZT. The corresponding E_m-factors were to be about 1.4.

The experiments with combined interlayers of rubber or GAP and an additional 1–2 mm thin layer of the high explosive Dottikon showed that GAP can be forced to undergo a chemical reaction by a high explosive nearby and that therefore GAP + Dottikon gives a stronger reaction than rubber + Dottikon. Figure 4 shows that a GAP layer together with a 2 mm thick Dottikon layer leads to a 23% smaller P_m value than a rubber layer together with a 2 mm thick Dottikon layer.

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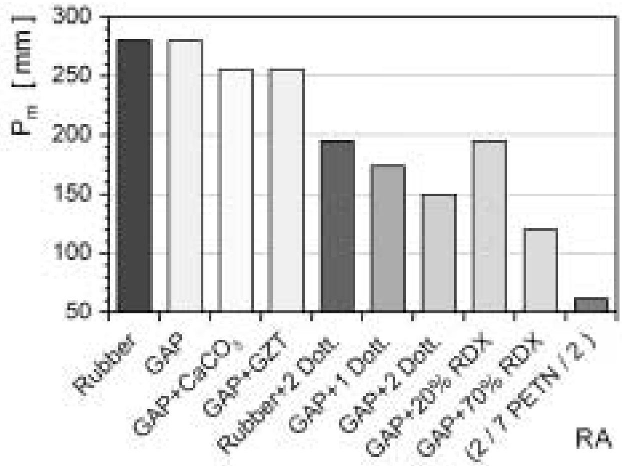

Figure 4: Penetration depth P_m versus type of reactive armor.

To avoid the use of a pure high explosive in a reactive armor interlayer it now seemed reasonable to test homogeneous mixtures of GAP and a high explosive. We chose RDX as high explosive and carried out experiments with reactive armor sandwiches containing interlayers of GAP + 20% RDX and GAP + 70% RDX. With these mixtures reductions of penetration depth of 30% and 57% compared to rubber could be reached (see Fig. 4). The corresponding E_m-values can be calculated to be 1.8 and 3.0, respectively.

The flash X-ray photographs of figure 5 show the interactions of the shaped charge jet with reactive sandwiches filled with GAP + GZT, GAP + 20% RDX and GAP + 70% RDX and the jet disturbance behind the sandwiches. At GAP + GZT the flyer plates strongly bulge apart due to high pressures created in the interlayer by the very fast impact of the shaped charge jet. The jet disturbance is almost as small as at GAP + Desmodur. In case of GAP + 20% RDX the jet disturbance becomes much greater. This is due to the effect, that now the flyer plates not only bulge apart but even fly apart because of the energy released in the energetic composite material. The jet disturbance is still enhanced by using 70% RDX instead of 20% RDX as can be clearly seen in the last photo of Figure 5.

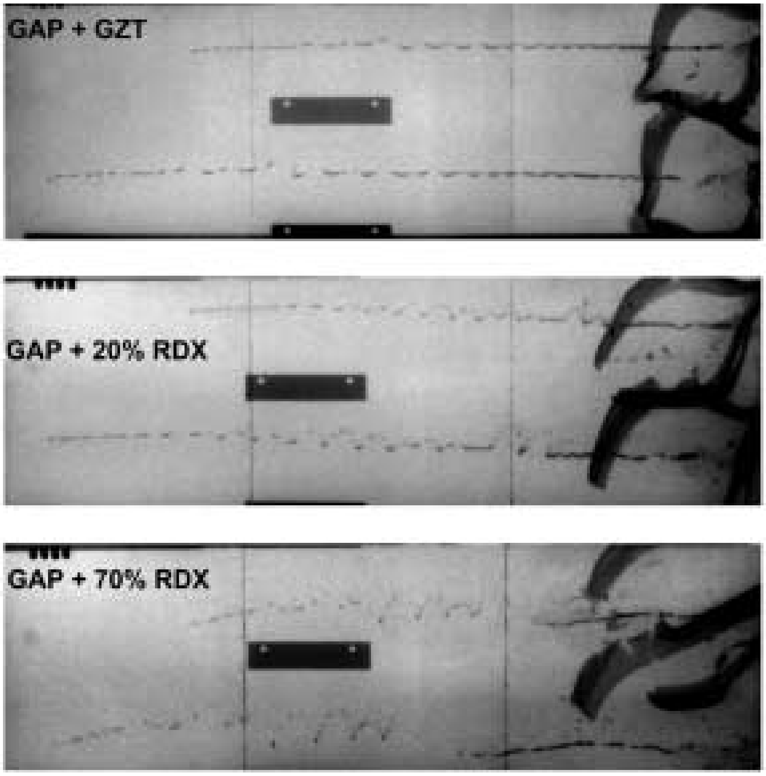

Figure 5: Interaction of a shaped charge jet with sandwiches containing GAP + GZT, GAP + 20% RDX and GAP + 70% RDX.

To be able to evaluate the potential danger arising from reactive armor containing mixtures of GAP and RDX by [4] sensitivity measurements were performed. It was found that the values of impact sensitivity and friction sensitivity are 10 Nm and 360 N for GAP + 20% RDX and 5 Nm and 168 N for GAP + 70% RDX. The former values are not but the latter values are values of typical high explosives (see [5] e.g.).

However, comparison of the penetration depth P_m behind a sandwich containing a 10 mm thick layer of GAP + 70% RDX with P_m behind a sandwich containing a 7 mm thick layer of pure high explosive PETN (see the two right bars of Fig. 4) indicates that the brisance even of the 70% RDX mixture seems to be much smaller than that of a pure high explosive. For a concluding evaluation of the danger potential it must be still investigated how sensitive GAP + RDX mixtures are with respect to heat and shock.

CONCLUSION

Mixtures of GAP and RDX seem to offer a suitable and adjustable material for reactive armors against shaped charge threats. Their reactivity at impact of a shaped charge jet can be controlled by the fraction of RDX in the composite mixture. By refining the geometrical construction of the sandwich system and the chemical composition of the interlayer material reactive armor based on sandwiches with GAP + RDX interlayers may become an effective means for the protection of light armored combat vehicles.

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