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Research of ERAWA-1 and ERAWA-2 Reactive Cassettes

Adam WIŚNIEWSKI

Military Institute of Armament Technology,
7 Prymasa Stefana Wyszyńskiego Str., 05-220 Zielonka, Poland
Author's e-mail address and ORCID:
adam.wisniewski@witu.mil.pl; https://orcid.org/0000-0003-1795-2422

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Abstract. In the paper there are presented general parameters of shaped charge projectiles (SC) and explosively formed projectiles (EFP), designed for destroying of armed vehicles, and parameters of explosive reactive armours (ERA), which significantly increase capability of protection of rolled homogeneous armour (RHA) against piercing by these projectiles. There are shown examples of destruction of tanks not protected by the ERA. Their parameters are presented on the base of ERAWA-1 and ERAWA-2 Polish reactive cassettes for PT-91 Hard tank. There are described the following requirements: capability of protection of ERAWA-1 and ERAWA-2 cassettes as a result of reaction in the static test of shaped charge projectiles PG-7 and 125 mm BK-14M, effect in the dynamic test of 125 mm BM-15 projectile that pierces through due to its kinetic energy, and resistance to detonation of the cassettes fired by 12.7×107 mm AP B-32 projectiles. There are demonstrated results of the resistance to detonation of the neighbouring ERAWA cassettes in case of detonation of the central cassette in the panel.

There are presented results of test of resistance to detonation of the ERAWA cassettes while burning on them flammable material (gasoline, napalm), and resistance to detonation of the cassettes dropped from 3 m height onto a hard substrate of RHA. The safe distance for humans after detonation of the projectile and ERAWA-2 cassette was also tested.
Key words: armour penetration, ERA armour, ERAWA-1 armour, ERAWA-2 armour

1. INTRODUCTION

Strong "competition" between the protection capability of the RHA (*Rolled Homogeneous Armour*) and penetrating capability of the projectiles, especially shaped charge projectiles (SC) (having energy $E_{max} \leq 10$ MJ and calibre d = 70-155 mm) has led to achieve maximum depth of penetration $DP_{ref} \geq 10d$ [1, 2], where (DP_{ref}) is reference RHA.

Explosively formed projectiles (EFP) with calibre d = 50-200 mm can create similar danger for heavy and light armoured vehicles (tanks, light fighting vehicles LFV, etc.). The projectiles are usually used to attack vehicles from top, lateral and rear sides, with energy $E_{max} \leq 10$ MJ, and which DP_{max} = 1*CD* (*CD* – cone diameter of projectile) is not too high, but maximum crater diameter of the penetration into the RHA is very high $Ø_{max} \leq 1CD$ [1, 2].

At present none of only metal and/or composite armour of a vehicle can stop full penetration of the thickest front armour of these tanks. The most efficient way of protection of the armoured vehicles (e.g. tanks) is to use explosive reactive amours (ERA) in form of metal cassettes (boxes) with explosive [3, 4]. After perforation of the ERA cassette casing, the shaped charge jet initiates explosive inside. The detonation energy of the explosive together with launched casing make strong dispersion of the jet and after penetration of the cassette the RHA perforation capability decreases significantly, even of >50 % [5÷8].

There are lots of examples of tanks destroyed after hitting of them by the SC ammunition, e.g. guided missiles [9, 10] or PG-7 launched from RPG-7.

According to the Israel data during the 2006 war with Hezbollah in Lebanon the tanks Merkava (without ERA) were hit by guided missiles (ATGMs - Anti-Tank Guided Missiles). Among them in 25 cases the armour was penetrated (mainly by Metys-M projectiles), as a result, 5 tanks were destroyed [9, 10].

Turkey's alleged military vehicle losses in Syria, that started making rounds in 2016, are presented in Table 1 [11, 12]. Among other things, the Leopard 2A4 tanks without ERA cassettes were destroyed after hitting by anti-tank missiles.

In Military Institute of Armament Technology in Zielonka (Poland) the author worked out three generations of reactive cassettes ERAWA-1 and ERAWA-2 for PT-91 Hard tank (Fig. 1) [13÷16].

Table. 1. The example - Turkey's alleged military vehicle losses in Syria, that started making rounds in December 2016 [11, 12]

No.	Type of tank	Plate	Unit	Comments
1	Leopard 2A4	195535	1/2nd Arm. Brig.	Hit by anti-tank missile
2	Leopard 2A4	195536	1/2nd Arm. Brig.	Hit by anti-tank missile
3	Leopard 2A4	195556	1/2nd Arm. Brig.	Hit by anti-tank missile
4	Leopard 2A4	195586	1/2nd Arm. Brig.	Hit by anti-tank missile
5	Leopard 2A4	195591	1/2nd Arm. Brig.	Hit by anti-tank missile
6	M60T	264944	1/16th Mech. Brig.	Hit by anti-tank missile
7	TTZA Kobra	259447	20th Arm. Brig.	Hit by anti-tank missile

Fig. 1. PT-91 Hard tanks during military parade in Warsaw, August 15, 2017

For destroying of the ERA armours HEAT-RA (*High Explosive Anti-Tank Reactive Armour*), the tandem shaped charge projectiles were developed, of which the first head destroys this armour and the second head pierces the uncovered armour of the armoured vehicle RHA [13]. For protection against such projectiles the ERAWA-2 cassettes, consisting of layers of explosive, tested both in the static and dynamic conditions, were used in Polish (PT-91 Hard) and Malaysian tanks.

2. TESTING OF PROTECTION CAPABILITY OF ERAWA CASSETTES

The aim of test was determination of the protection capability of ERAWA-1 and ERAWA-2 cassettes from the current production, and their resistance to thermal and mechanical exposures, which can occur at the battle field. The cassettes ERAWA-1 and ERAWA-2 were fixed to stands, the same as are mounted on the PT-91 Hard tank. The stands were placed on the RHA plate of 1200×1200×150 mm size.

The required protection capability of these cassettes was checked against impact of missiles in static tests (PG-7W and 125 mm BK-14M) and in dynamic tests (125 mm BM-15).

The tests of resistance to detonation of the cassettes as a result of firing with 12.7×107 mm AP B-32 projectiles were also carried out.

It was also tested the resistance to detonation of neighbouring cassettes in case of detonation of the central panel cassette, resistance to detonation of cassettes as a result of burning flammable material on them (gasoline, napalm), resistance to detonation of cassettes as a result of dropping them from a height of 3 m onto a hard RHA substrate. The safe distance for humans after detonation of the projectile and ERAWA-2 cassette was also tested.

In the above mentioned dynamic tests, a 125 mm tank gun 2A46 and a 12.7 mm large-calibre machine gun were used. The ERAWA cassettes were fixed on stands of 9 cassettes (3×3) and 16 cassettes (4x4), which were mounted on the RHA armour plates.

Protection capability of the reactive cassette *PC* (*Protection Capability*) is calculated as:

$$PC = 1 - (DP/DP_{\mathrm{ref}}) \times 100\ \% \qquad (1)$$

where: DP - depth of penetration, DP_{ref} - referential depth of penetration.

Tables 2÷6 and Figures 2÷6 present results of tests of protection capability of the ERAWA cassettes, fixed on stands and placed on the RHA armour, with the use of the PG-7W, 125 mm BK-14M and 125 mm BM-15 projectiles.

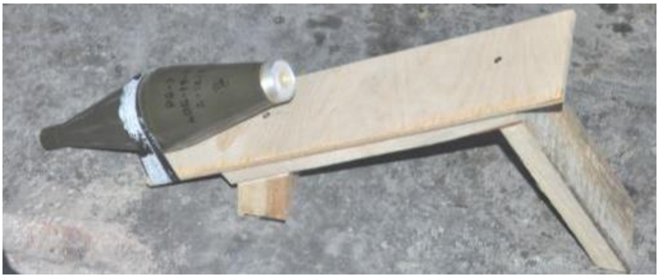

Fig. 2. The PG-7 projectile set under angle $\alpha_{\mathrm{NATO}} = 60^{\mathrm{o}}$ on two RHA plates

Fig. 3. The BK-14M projectile set under the angle of $\alpha_{\mathrm{NATO}} = 60^{\mathrm{o}}$ on two RHA plates

Table 2. The results of static test of protection capability of the ERAWA cassettes with the use of the PG-7 projectiles (DP_{ref} = 330 mm)

No.	Type of ERAWA cassette/ RHA thickness, mm	Angle of firing of the armour, α_{NATO}, °	Depth of RHA penetration, *DP*, mm	Protection capability of the cassette, *PC*, %
1	- / 300 (2×150)	60	330	-
2	ERAWA-1 / 300 (2×150)	60	10.8	96.7
4	ERAWA-2 / 300 (2×150)	60	4.4	98.6

Fig. 4. The BK-14M projectile set under the angle of $\alpha_{NATO} = 60^o$ on the ERAWA-2 cassette fixed on a stand placed on two RHA plates

Table 3. The results of static test of protection capability of ERAWA cassettes with the use of the BK-14M projectiles (DP_{ref} = 540 mm)

No.	Type of ERAWA cassette / RHA thickness, mm	Angle of firing of the armour, α_{NATO}, °	Depth of RHA penetration, *DP*, mm	Protection capability of cassette, *PC*, %	Remarks
1	- / 300 (2x150)	60	540	-	
2	- / 300 (2x150)	60	455	-	
3	- / 300 (2x150)	60	460	-	Outlet of shaped charge jet on the side of RHA2 plate
4	ERAWA-1 / 300 (2×150)	60	300 (RHA1)	44.4	No penetration of RHA2 plate
5	ERAWA-1 / 300 (2×150)	60	300 (RHA1)	44.4	No penetration of RHA2 plate
6	ERAWA-2 / 300 (2×150)	60	170	68.5	

a) b)

Fig. 5. Test of detonation of the central ERAWA-2 cassette in the panel of 9 ERAWA-2 cassettes (3×3), mounted on a stand an placed on the RHA, with the use of the PG-7W projectile: a) before detonation of the PG-7W projectile, b) trace after detonation of the PG-7W projectile and one ERAWA-2 cassette, and also other cassettes torn out from the stand

Table 4. The results of static test of resistance to detonation of 9 ERAWA-2 cassettes (3×3) after detonation of the central ERAWA-2 cassette with the use of the PG-projectile

No.	Number of ERAWA cassette in panel / thickness of RHA, mm	Angle of firing of the armour, α_{NATO}, °	Depth of penetration of RHA, *DP*, mm	Protection capability of cassette, *PC*, %
1	9 (3×3) ERAWA-2 / 150	60	5	98.4

a) b) c)

Fig. 6. Test of firing with the 125 mm BM-15 projectiles: a) 2 panels of 16 ERAWA-2 cassettes (4×4) before firing, b) the RHA plate after firing, c) panel after firing with not mechanically destroyed ERAWA-2 cassette

It was also checked, that the neighbouring ERAWA-1 and ERAWA-2 cassettes in relation to the cassette fired with the 12.7×107 mm AP B-32 projectiles (fired from a 12.7 mm large-calibre machine gun from a distance of 30 m at $\alpha_{\mathrm{NATO}} = 0^{\circ}$) did not detonate.

Table 5. The results of dynamics tests of ERAWA-2 cassettes with the use of BM-15 projectiles (DP_{ref} = 300 mm) launched from 125 mm tank gun 2A46

No.	Type of ERAWA cassette / RHA thickness, mm	Angle of firing of the armour, α_{NATO}, ^{o}	Depth of RHA penetration, *DP*, mm	Protection capability of cassette, *PC*, %	Remarks
1	ERAWA-2 / 300 (2x150)	70	170	43.3	Firing of 2 panels 2× (4×4) of the ERAWA-2 cassettes from 100 m distance.

Table 6. The results of static test of resistance to detonation of ERAWA cassettes after burning on them fuel and napalm during t_{min}>10 minutes

No.	Type of ERAWA cassette	Thickness of burned layer, *h*, mm	Burning time, *t*, minutes	Resistance to detonation %	Remarks
1	ERAWA-1	10	> 10	100	Unimpaired cassette after fuel burning
2	ERAWA-2	10	> 10	100	Unimpaired cassette after fuel burning
3	ERAWA-1	10	> 10	100	Unimpaired cassette after napalm burning
4	ERAWA-2	10	> 10	100	Unimpaired cassette after napalm burning

In case of use of two panels of 2×16 ERAWA-2 cassettes (4×4), the neighbouring ERAWA-2 cassettes in relation to the cassette hit with the 125 mm BM-15 projectiles (launched from the 2A46 tank gun from a distance of 100 m at α_{NATO} = 70^{o}) did not detonate.

Determination of resistance to detonation of ERAWA-1 and ERAWA-2 cassettes (a cassette after burning of napalm) as a result of their drop onto a hard substrate (10 mm thick RHA plate) from a height of 3 m was also performed. During this test, the cassettes did not detonate and were not damaged.

In addition, a safe distance for humans was checked, because at a distance of 400 m from the PG-7W projectile explosion and after detonation of the central ERAWA-2 cassette 9 panels ERAWA-2 (3×3) (Table 2) on 20 cardboard shields (2.5×1.5 m size) there was no sign of piercing by shrapnel.

3. CONCLUSIONS

On the basis of the obtained results, the following conclusions can be drawn:

1. In the static test of ERAWA cassettes fixed on stands and placed on the RHA, with the use of the PG-7 projectiles (DP_{ref} = 300 mm), the following protection capacities were obtained: CP=96.7 % for the ERAWA-1 cassette and CP = 98.6 % for the ERAWA-2 cassette. These cassettes meet the protection requirements for firing angles $\alpha_{NATO} = 60^{o}$.
2. In the static test of the ERAWA-2 cassettes fixed on a stand and placed on the RHA, with the use of BK-14M projectiles (DP_{ref} = 540 mm), the protection capacity CP = 68.5 % was obtained. These cassettes meet the protection requirements for firing angles $\alpha_{NATO} = 60^{o}$.
3. In the dynamic test of ERAWA-2 cassettes fixed on a stand and placed on the RHA, with the use of BM-15 projectiles (DP_{ref} = 300 mm), the protection capacity CP = 43.3 %. These cassettes meet the protection requirements for firing angles $\alpha_{NATO} = 70^{o}$.
4. In the dynamic firing test of ERAWA-1 and ERAWA-2 cassettes, fixed on a stand and placed on the RHA, with the use of 12.7x107 mm AP B-32 projectiles from a distance of 30 m, resistance to detonation of 100 % of these cassettes was achieved. These cassettes meet the requirements of resistance to detonation for firing angles $\alpha_{NATO} = 0^{o}$.
5. In the static test of the ERAWA-1 and ERAWA-2 cassettes, as a result of burning napalm on them, resistance to detonation of 100 % of these cassettes was obtained. These cassettes meet the requirements of resistance to detonation while burning on them 10 mm layer of napalm during > 10 min.
6. In the static test of the ERAWA-1 and ERAWA-2 cassettes, as a result of burning of gasoline on them, resistance to detonation of 100 % of these cassettes was obtained. These cassettes meet the requirements of resistance to detonation while burning 10 mm layer of gasoline on them during > 10 min.
7. In the dynamic test of the ERAWA-1 and ERAWA-2 cassettes, as a result of their drop onto a hard substrate (RHA of >100 mm thickness) from a height of 3 m, resistance to detonation of 100 % of these cassettes was obtained. These cassettes meet the requirements for resistance to detonation after drop from a height of 3 m onto a hard substrate (RHA plate of 150 mm thickness), the cassettes were not mechanically damaged and can be used for protection of the vehicle.
8. In the static test of detonation of the central ERAWA-2 cassette in a panel of 9 ERAWA-2 (3×3) cassettes, fixed on a stand and placed on the RHA, with the use of the PG-7 projectile (DP_{ref} = 300 mm), resistance to transmission of detonation to neighbouring cassettes of 100 % was

obtained. These cassettes meet the resistance requirements for to transmission of detonation in a panel of 9 cassettes ERAWA-2 (3×3).

9. In the dynamic test for the distance of fragmentation of debris from detonation of central ERAWA-2 cassette in a panel of 9 ERAWA-2 (3×3) cassettes, and detonation of the PG-7 projectile, it was obtained 100 % safety to impact of cardboard shields at a distance of 400 m. Therefore, the requirements for safe distance to humans and equipment are met at a distance of 400 m from the detonating ERAWA-2 cassette and the PG-7 projectile.

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Badania kaset reaktywnych ERAWA-1 i ERAWA-2

Adam WIŚNIEWSKI

Wojskowy Instytut Techniczny Uzbrojenia
ul. Prymasa Stefana Wyszyńskiego 7, 05-220 Zielonka

Streszczenie. W artykule przedstawiono ogólne parametry pocisków kumulacyjnych (*Shaped Charge* - SC) i pocisków formowanych wybuchowo (*Explosively Formed Projectiles* - EFP) służące do niszczenia pojazdów opancerzonych oraz parametry pancerzy reaktywnych (*Explosive Reactive Armour* - ERA), które w znacznym stopniu zmniejszają zdolność przebicia homogenicznych stalowych pancerzy (*Rolled Homogeneous Armour* - RHA) tych pocisków. Pokazano przykłady zniszczenia czołgów, które nie były chronione pancerzem reaktywnym (ERA). Na przykładzie polskich kaset reaktywnych ERAWA-1 i ERAWA-2 dla czołgu PT-91 Twardy zaprezentowano ich parametry. Określono następujące wymagania: zdolność ochronną kaset ERAWA-1 i ERAWA-2 w wyniku oddziaływania w teście statycznym pocisków kumulacyjnych PG-7 i 125 mm BK-14M, oddziaływania w teście dynamicznym 125 mm BM-15 pocisku przebijającego swoją energią kinetyczną oraz odporności na detonację kaset w wyniku ostrzału pociskami przeciwpancernymi (*Armour Piercing* - AP) 12.7x107 mm typu B-32. Pokazano wyniki badań odporności na detonację sąsiednich kaset ERAWA w przypadku detonacji środkowej kasety panelu. Przedstawiono wyniki badań odporności na detonację kaset ERAWA w wyniku palenia się na nich materiału łatwopalnego (benzyny, napalmu); odporności na detonację kaset w wyniku zrzucania ich z wysokości 3 m na twarde podłoże RHA. Badano również odległość bezpieczną dla ludzi po detonacji pocisku i kasety ERAWA-2.

Słowa kluczowe: przebicie pancerza, pancerz ERA, pancerz ERAWA-1, pancerz ERAWA-2