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Ballistic behavior of multilayer wire mesh application armor

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ABSTRACT

In this paper, an attempt was made to increase the ballistic protection of the armor system by combining non-homogenous spaced armor in form of multilayer wire mesh with rolled homogenous armor steel base plate. Different angles of incidence were tested: 0, 20, 25 and 35º, by using 12.7 mm armor piercing incendiary ammunition from 100 m. It was found that the inclination of the armor system has a negative effect on ballistic resistance due to variations in wire body-to-body distance, some of which can increase, causing a decreased contact with the projectile and an insufficient yaw. The yaw causes a sideways impact on the base plate. However, the non-penetrating hits in vertical armor cause a more severe damage on the base plate compared to the inclined armor system. This effect is due to the inclination itself, which is a common behavior of increasing effectiveness of sloped armor

Key words: *ballistic testing; wire mesh; spaced armor*

1. INTRODUCTION

Local military conflicts and peace keeping missions stressed the significance of survivability of armored vehicles. Most Cold-war era vehicles that are still in use today were designed to stop rifle or general-purpose machine gun calibers such as 7.62x51 and 7.62x54R [1,2]. Furthermore, the significance of logistic support means that trucks and specialized transportation vehicles were frequently equipped with improvised armor protection [3-5]. However, modern tungsten – carbide (WC) cored ammunition and the application of heavy machine guns usually mounted on commercial flat-bed trucks and pick-ups proved to be a common sight in Somalia, Iraq and Afghanistan. Also, the wider proliferation of heavy machine-gun caliber anti-material rifles is expected. These larger calibers such as 12.7x99 and 12.7x108 mm penetrate roughly twice as much as 7.62 mm ammunition and have ranges greater than 1000 m, making them more accurate and longer-ranged than of rifle propelled grenades (RPG) [6-8]. Finally, the increased significance of urban areas where an increased portion of population lives, makes heavy machine-guns and anti-material rifles even more attractive, due to their ability to be fired from enclosed spaces [9,10]. Logistic or armored vehicles are frequently field-modified with simple addition of mild steel or preferably rolled homogenous armor (RHA) plates. This adds to the vehicle weight, limiting its payload. Several alternatives were found, such as ceramic armor or perforated plates [11-13]. Although their mass effectiveness is higher than that of RHA, their cost and production time are significant. Therefore, it is of utmost importance to use readily available products, which can be relatively quickly transformed into a usable add-on or appliqué armor. Wire mesh would, therefore, act as spaced armor that could induce yaw on passing projectiles even if homogenous [14]. Furthermore, spaced armor can also increase the armor system resistance to shaped charge warheads common for RPGs and anti-tank guided missiles (ATGMs), particularly from older types [15].
The aim of this paper is to study the applicability of wire mesh as appliqué armor. A particular attention was paid to the mounting angle and the possibility to increase armor protection of armor system from 7.62 armor piercing (AP) to 12.7 mm armor piercing incendiary (API) ammunition

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2. EXPERIMENTAL

2.1 Specimen preparation

Armor system used in this study is shown in Fig. 1 and 2. Appliqué armor model was made of wire mesh made of 6 mm mild steel wires with mechanical properties shown in Table 1, with four mesh layers placed in a L-profile welded frame (50x50x4 mm), Fig. 2. Wire meshes were placed in a step-up configuration to decrease the distance between centers of wires from the initial 67 mm to 16.75 mm, or 10.75 mm between the wire bodies, Fig. 3. The wire mesh spaced armor module had the dimensions of 700x400 mm and was welded on the 13 mm basic plate, at the distance of 400 mm, Fig. 1. The basic plate mechanical properties are given in Table 1. As such, the basic plate, set at 0^o protects from 7.92 mm Spitzgeschoss mit Kern (SmK), which is equivalent to the protection from 7.62x51 and 7.62x54R AP ammunition [8]. Four armor arrangements were tested, with various angles of incidence of the whole armor system: 0, 20, 25 and 35.

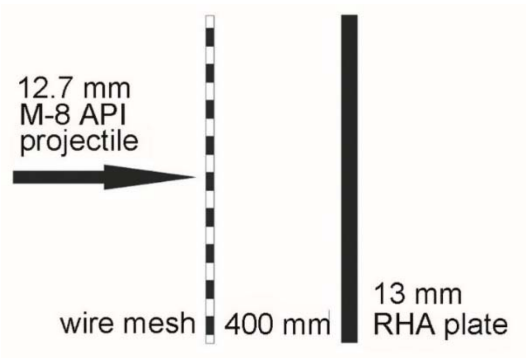

Fig 1 *The basic schematic of the target.*

Fig. 2 *Target setup ready for ballistic testing.*

Table 1. *Mechanical properties of wire mesh and basic plate*

	Yield strength [MPa]	Tensile strength [MPa]	Elongation [%]	Hardness BHN
Wire mesh	260	380	19	120
Basic plate	1410	1630	9	460

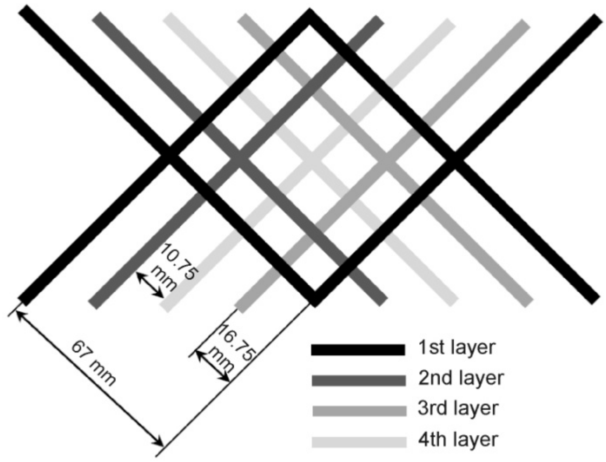

Fig 3 *Wire mesh arrangement.*

2.2 Ballistic testing

The schematic depiction of ballistic testing experiment setup is shown in Fig. 2. The ballistic testing was performed with Browning M2HB heavy machine gun placed 100 m from the armor system on a tripod. The resistance of armor system was tested by using 12.7x99 mm M8 API ammunition with the projectile diameter of 12.9 mm [16]. The penetrating core of this ammunition is made of steel, with hardness of 51 HRc, with a diameter of 10.9 mm and the length of 47.2 mm. Each armor system setup was tested with five shots. The equivalent firing distance was determined in accordance to the procedure shown in Balos et al. [4].

To determine ballistic resistance of armor systems, the description of basic plate damage was used. To do this, the following descriptions were used:

1. Hole Normal – A complete hole through the basic plate
2. Cracked Bulge – A bulge on the back of the plate with at least one distinct crack on it
3. Smooth Bulge – A bulge on the back of the plate without cracks

However, cracked bulge description was found to be insufficient, since in some instances, the number of cracks varied. It was determined that the development of two cracks was a more severe damage to the basic plate than the development of one crack. Therefore, cracked bulge phenomenon was accompanied with the depiction of the number of cracks that developed during the process of ballistic testing

3. RESULTS

3.1 Ballistic testing

The results of ballistic testing in respect of the target angle, the muzzle velocity, the equivalent firing distance, the mesh number impacted and with the description of basic plate damage are shown in Table 2. It can be seen that muzzle velocities measured were lower than the reference value of 910±15 m/s [8], which rendered necessary to find the equivalent firing distance. In Table 2, it can be seen that equivalent firing distances are from 137 – 219 m. Although it was impossible to accurately determine the exact point of impact, the mesh layer that suffered impact was reported in Table 2.

The description of basic plate damage refers to the phenomenon that can be observed on the back of the basic plate. It can be seen that a vertical armor system (0^o from vertical) offers full protection in accordance to SNO 1645 standard [8], with five projectiles out of five stopped at the basic plate. When inclined at 20^o, the ballistic resistance is lowered, with one hole normal, that is full penetration of the basic plate. Higher inclinations of 25 and 35^o results in a further ballistic resistance degradation with two and three holes normal on the base plate out of five shots fired. Another indication of ballistic resistance is the phenomenon's when the API projectile is stopped.

Table 2. *Mechanical properties of wire mesh and basic plate*

No.	Target angle [°]	Muzzle velocity v_{10} [m/s]	Equivalent firing distance [m]	Impact on mesh No.	Description of basic plate damage
1		870.4	157	2	Cracked bulge
2		857.7	185	3	Cracked bulge
3	0	858.3	184	1	Cracked bulge
4		860.5	182	4	Cracked bulge (two cracks)
5		869.3	159	3	Smooth bulge
6		879.5	137	2	Smooth bulge
7		862.8	174	1	***Hole normal***
8	20	847.5	209	2	Smooth bulge (two cracks)
9		858.7	184	3	Cracked bulge
10		861.0	176	4	Cracked bulge
11		858.0	185	4	Cracked bulge
12		869.2	160	1	Smooth bulge
13	25	846.7	210	4	Smooth bulge
14		856.2	186	3	***Hole normal***
15		863.2	173	2	***Hole normal***
16		874.2	147	4	***Hole normal***
17		865.4	171	3	***Hole normal***
18	35	859.1	182	1	Smooth bulge
19		844.2	212	2	***Hole normal***
20		866.8	167	2	Smooth bulge

Contrary to the previously reported results, the increase in armor system inclination renders the occurrence of a more frequent smooth cracked bulge. This suggests that vertical armor offers a higher ballistic resistance, but the damage caused by non-penetration hits is higher than that of the inclined armor system.

3.2 Macro imagery

The impact on wire mesh is shown in Fig. 4. It can be seen that individual wires become bent and fractured, receiving a hook-like shape, as the projectile passes through the spaced armor. As a result, in the projectile yaw is induced, as a result of non-homogenous stresses. The generated yaw influenced that under optimal condition, the projectile impacts the base plate sideways. In this case, the area of the projectile or the penetrating core is significantly larger than without yaw. Therefore, the projectile can be stopped by the base plate, which would otherwise be impossible. However, if the yaw is not pronounced, the penetrating core can penetrate the base plate. Different cases of penetrating and non-penetrating hits on the base plate can be seen on Figs. 5 and 6.

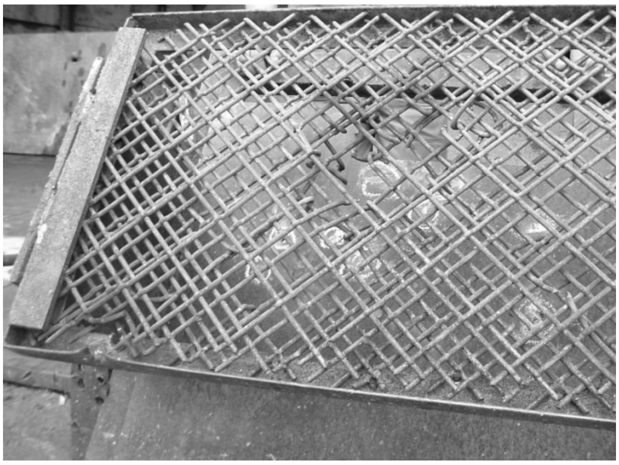

Fig 4 *The impact on wire mesh.*

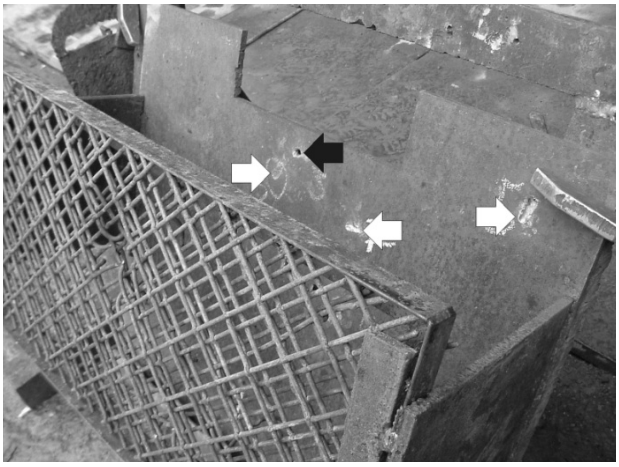

Fig 5 *The impact on the outer part of the base plate. White arrows show non-penetration impacts and black arrow show the penetration impact.*

4. DISCUSSION

The results presented in this paper show a clear correlation between the inclination and the ballistic effectiveness of the armor system. As armor system is consisted of the wire mesh made of four interleaved layers to lower the distance between the wire bodies, the inclination of this system, influences two major issues. The first is that the inclination makes the wire body to the wire body distance between layers change, in some places it decreases, but in others increase. This increase can potentially match or even become larger than the projectile diameter, which means that the passing projectile may not even achieve contact with wires. On the other hand, inclined wires represent more effective yaw inducers. Furthermore, an inclined armor system also increases the effectiveness of the base plate, making it more resistant than when mounted vertically. The mentioned advantages and drawbacks of armor inclination are in full correlation with the results of ballistic testing. Vertical armor provides an overall higher ballistic effectiveness and it is the only one tested that complies with the requirements set in SNO 1645 [8]. However, the damage on the base plate is higher than non-penetrating hits in the inclined armor system.

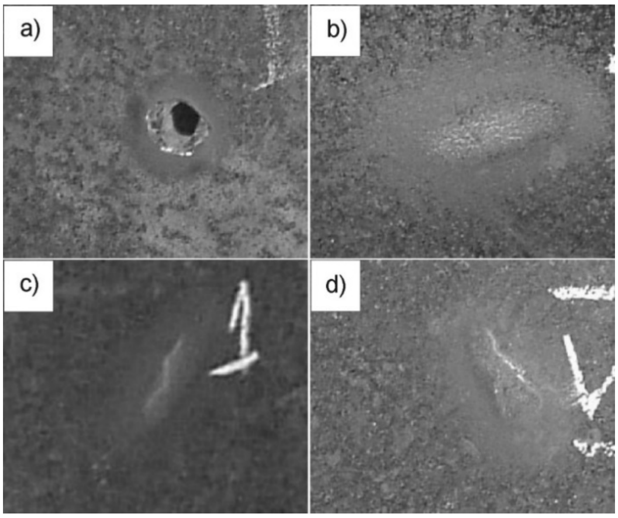

Fig 6 *The inner part of the base plate: a) shot 14, hole normal; b) shot 7, smooth bulge; c) shot 1, cracked bulge; d) shot 8, cracked bulge (two cracks).*

The destabilizing effect is present regardless of the layer of the mesh under impact. That means, non-penetrating hits occurred after hits on any of the four interleaving meshes in vertical armor. Similarly, penetrating hits into base plate of the inclined armor systems (20; 25; 35°) occurred after impact into any of the four meshes. Furthermore, variations in muzzle velocity also have a secondary influence on ballistic resistance.
As such, it can be stated that the ballistic resistance of multi-layer wire mesh relies on yaw, which is similar to the results obtained with wire fences made of high strength patented wire suspended in welded L-profiles, as reported in Balos et al. [4]. However, this is in contrast to perforated plates, which rely on the fracture of the hard, but also brittle penetrating core. The fracture occurs as a result of bend stresses induced by the edge effect of the holes made in the plate [11,17,18]. Mass effectiveness of different non-homogenous types of spaced armors is shown in Table 3. Mass effectiveness is the ratio between areal densities of the RHA (in this case 460 BHN as the base plate, 220 kg/m2) and the tested armor.

Table 3 *Perforated plates, wire fence and wire mesh geometrical parameters and mass effectiveness's*

Non-homogenous armor	Perforated plates		Wire fence	Wire mesh
	H9-6-0[17]	H11-6-0[18]	PS20[4]	
Yield strength [MPa]	1255	1255	1410	260
Tensile strength [MPa]	1450	1450	1630	380
Elongation [%]	11	11	9	19
Perforation diameter or the distance between the wires [mm]	9	11	8.5	10.67
Perforated plate thickness or fence wire diameter [mm]	6	6	5	6
Inclination [°]	0	0	20	0
Spaced armor areal density [kg/m^2]	28	23	26	35
Armor system areal density (perforated plate + basic armor) [kg/m^2]	130	125	128	137
Perforated plate E_m compared to 460 BHN RHA	4.21	5.13	4.23	3.14
Armor system E_m compared to 460 BHN RHA	1.69	1.76	1.72	1.61

It can be seen that mass effectiveness of multilayer wire mesh is lower than that of wire fence made of patented wires and perforated plates made of high strength low alloy steel, Table 3. Another issue has to be addressed, the damage on the base plate. The impact in perforated plates causes the frequent fracture of penetrating core of the ammunition. That means, the damage on the base plate is relatively low and it is limited to smooth bulge [17,18]. On the other hand, the results of ballistic testing of wire mesh and basic plate suggest that a frequent cracked bulge occurs (Table 2), which can be considered as a considerably more severe, lowering multi-hit resistance of the armor system. However, the availability of mild steel used for wire mesh fabrication is wider and its cost is lower, which, in certain circumstances can be of decisive importance for improvising an increased ballistic protection of vehicles [5].

5. CONCLUSIONS

According to the presented results, some conclusions can be drawn:

- Multilayer wire mesh can be effective as an element of an appliqué armor system.
- Multilayer wire mesh induces yaw, causing the projectile to impact the base plate sideways, with a larger impact area than if the projectile would have impacted without yaw.
- The optimal target inclination is vertical, which offered full (five out of five) ballistic protection.
- The inclination, although increases the ballistic resistance of homogenous armor plates, has an adverse effect on ballistic resistance of armor system.
- The main cause of a decreased ballistic resistance of angled armor systems is related to a tri-dimensional character of multilayer wire mesh. Body-to-body wire distances increase in certain areas as a result of inclination, leading to an insufficient contact or the lack of it by the passing projectile and an insufficient yaw.
- Mass effectiveness of armor system based on a combination of multilayer wire mesh made of mild steel is lower than that of patented wire fences and perforated plates, due to lower mechanical properties of the material.

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