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Ballistic Resistance of Steel Plate Hardox upon Impact of Non-Penetrating Projectiles

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Abstract:

A steel plate material Hardox can be used also as a core design material for the production of ballistic barriers or traps at the shooting ranges for small arms. The article deals with the results of experiments with shooting weapon systems of a high ballistic performance and with Finite Element Method simulation of the projectile penetration upon the steel plate using the software Ansys Autodyn. Results and influencing factors are discussed.

Keywords:

Ballistics, bullet, Hardox, penetration, shooting experiment, simulation model

1. Terminal Ballistics of Targets upon the Impact of Non-Penetrating Projectiles

Evaluation of the terminal ballistics of barriers (armours, ballistics coverings, traps etc.) is one of the key goals for terminal ballistics of hard targets. The terminal ballistics of the barrier means the ability of the barrier to avoid the full penetration of the barrier upon the impact of ballistic object with specific energy (bullet or a part of it, fragment). The barrier is considered to be ballistic resistant in case of bringing the ballistic object to stop or pushing the object aside.

2. Introduction of the Steel Hardox

The steel Hardox made by SSAB Oxelösund, Sweden, is an abrasion resistant alloy steel of a high strength designated for wide machinery applications. The Hardox steel varies upon alloy components and the hardness. The basic range of the steel has the

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three-number code for determination of the Brinell hardness: 400, 450, 500 and 600. The increasing code number means higher hardness, abrasion resistance, tensile strength and on the other hand it means also decreasing ductility, toughness and weldability.

In terms of applications to the firing ranges HARDOX 450 material can be considered as an optimal compromise with regard to the requirements for high strength, hardness, toughness and weldability of material for the manufacture of ballistic screens of shooting ranges. For ballistic applications regarded as extreme shock loading, it is possible to consider the impact strength of the material HARDOX 450 as the limit value (i.e., steel HARDOX of the higher classes cannot be used with regard to their lower toughness and weldability).

Hardox 450 characteristics:

- Brinell hardness HBW 420-475, medium value HBW 450,
- Impact energy is 35 J using Charpy-V test at the temperature –40 °C,
- Carbon equivalent for the thickness 20 mm is 0.47 (CEV), respective 0.34 (CET),
- Yield strength R_e = 1200 MPa, tensile strength R_m = 1400 MPa,
- Elongation to fracture A_5 = 10 %.

Characteristics written above prove that the steel Hardox 450 exceeds the mechanical properties of common structural steels.

3. Experimental Shooting

3.1. Background of Shooting Experiments

For shooting experiments, a HARDOX 450 plate of the thickness of 10 mm only which is given ballistic limit of 6 500 J was used. It is therefore assumed that the plate captures the bullet impact with 6 500 J of energy. The goal of the experiments [1] was therefore to ascertain whether the presumption of safety capabilities of sheet metal HARDOX is real or not.

3.2. Characteristics of the Weapon Systems

Taking into account the above mentioned fact, systems for penetrating the sheets of HARDOX 450 reaching absolute ballistic limits mentioned above were selected with a minimum projectile calibre, thus with maximum specific energy. Under these circumstances the most unfavourable situation is reached in terms of capturing bullets. If the plates are ballistic resistant, it would be possible to assume that the plates will resist also different bullets of a larger calibre with the same impact energy.

For shooting to sheet the basic calibre weapon system 338 Lapua Magnum (8.6×69) with a sniper rifle TRG 42 (SAKO) were chosen as well as two types of charges with different types of bullets. Shooting was conducted at a distance of 15 m and 50 m. The conventional calibre projectile 338 LM is 8.6 mm and this value approximately corresponds to the actual diameter of the bullet.

The plate was shot at by projectile 338 Lapua Magnum with full metal jacket bullet FMJ with a commercial designation Lock Base and expansive projectile HP labelled Scenar (for both the manufacturer Lapua). Characteristics of both projectiles are listed in Tab. 1.

During shooting experiments with 10 mm plate were also used sniper rifles in calibre 308 Winchester (Rifle Sig Sauer SSG 3000), with an expansive ammunition HPBT (Diamond Line series) with a lead core and molybdenum coating of the weight of 10.9 g (NORMA manufacturer) and 7.62 × 54R (SVD Dragunov rifle, ammunition with armour-piercing/incendiary bullet from the military production of Sellier & Bellot).

Tab. 1 Characteristics of projectiles 338 Lapua Magnum (made by Lapua)

Characteristics	Dimension	Projectile	
		Lock Base (FMJ)	Scenar (HP)
Weight of bullet	g	16.2	16.2
Initial velocity	$m \cdot s^{-1}$	900	905
Initial energy	J	6561	6634
Initial specific energy	$MJ \cdot m^{-2}$	113	114
Velocity v_{200}	$m \cdot s^{-1}$	807	813
Energy E_{200}	J	5275	5354
Specific energy e_{200}	$MJ \cdot m^{-2}$	91	107

3.3. Realisation and Results of Experiments

For the shooting experiments, specially manufactured plates of HARDOX 450 of the thickness of 10 mm and square shape of side length 400 mm were used. When shooting, the evaluated plate was placed separately in a special single-purpose holder made for the purposes of experiments of steel profiles. The plate holder was backed along all four sides and fixed at the corners with 4 screws.

Targeting points were chosen on the face side plate so that the impact points were away of minimum 50 mm from the edge and of a minimum 70 mm from each other. For each shot, speed of the projectile before impact on a barrier through optical gates was measured.

The first shooting was an experiment carried out on one plate (with actual thickness of 10.0 mm to 10.2 mm) upon shooting of 7 bullets of calibre 338 Lapua Magnum from sniper rifle TRG 42, 5 full metal jacket boat tail bullets Lock Base and 2 expansion jacketed hollow point boat tail bullets Scenar. The test target was focused before shooting, so that 4 bullets impacted the plate in perpendicular direction (angle of impact measured from the perpendicular line to the plane of sheet 0°) and 3 bullets impacted the plate diagonally under impact angles 45 degrees, 30 degrees and 15 degrees (measured from the line perpendicular to the plane of sheet).

Next it was shooting to the same plate from sniper rifle Sig Sauer 3000 the projectile in calibre 308 Winchester with an expansive bullet Diamond line weighing 10.9 g. This calibre was used in the first experiment only for one approximate shot onto sheet perpendicular to the impact of the bullet. In all these cases shootings were held at a distance of 50 m.

The shooting experiment results did not ratify the above mentioned assumption of ballistic resistance of the sheet thickness of 10 mm against bullets with 6 500 J impact energy. The plate of thickness of 10 mm was shot at 10 m by both types of projectiles with calibre 338 Lapua Magnum with a surplus of energy. For the same sheet metal plate, however, only superficial damage caused by the projectile calibre 308 Winchester was recorded.

Fig. 1 shows front side of the sheet after a total of 8 shots. The characteristic of the effect of bullet on the plate is given according to the serial number of the shot.

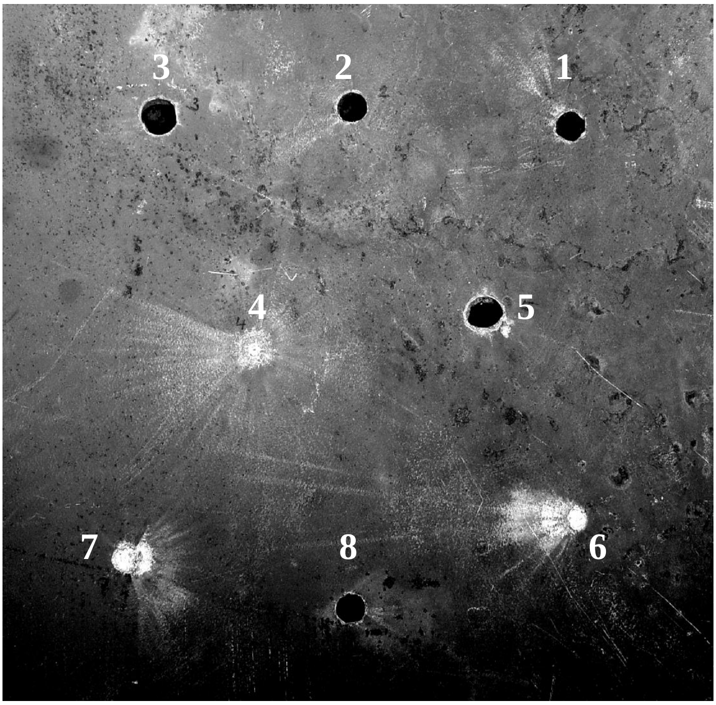

Fig. 1 Looking at the front (shot) side of the sheet HARDOX 450 of the thickness 10 mm after shot with high-performance rifle ammunition (in the figure is cut out – total board size is 400 mm ´ 400 mm).

1. *top right – bullet hole – projectile 338 LM/FMJ, perpendicular impact of the bullet to the frontal target area, the mean diameter of the inlet 11.8 mm,*
2. *top centre – bullet hole – projectile 338 LM/FMJ, perpendicular impact, the mean diameter of the input hole 12.3 mm,*
3. *top left – bullet hole – projectile 338 LM/HP, perpendicular impact, the mean diameter of the input hole 20.4 mm with unilateral narrowing to 19 mm,*
4. *centre left – no bullet hole – very shallow nick (maximum 0.1 mm) – projectile 308 Win/FMJ, perpendicular impact, the mean diameter of mechanically affected area 4.5 mm,*
5. *centre right – bullet hole – projectile 338 LM/HP, perpendicular impact, elliptical input hole 11.5 mm ´ 20 mm,*
6. *bottom right – no bullet hole – shallow nick (maximum 0.5 mm), projectile 338 LM/FMJ, sloping impact of bullet at an angle of 45 degrees, mechanically affected zone of elliptical shape 6.5 mm ´ 9 mm,*
7. *bottom left – no bullet hole – deep nick (maximum 1.8 mm), projectile 338 LM/FMJ, sloping impact of bullet at an angle of 30 degrees (regarding to perpendicular line to the plane of the plate), the mean diameter of mechanically affected area 11 mm,*

8. *bottom in the middle – bullet hole – projectile 338 LM/FMJ, sloping impact at an angle 15 degrees (regarding to perpendicular line), the mean diameter of the input hole 11.5 mm.*

As it is apparent from the previously shown picture, the bullets of calibre 338 Lapua Magnum (full metal jacketed and expansive as well) with lead cores with impact energy around 6 000 to 6 200 J have penetrated the 10mm plate in the normal impact with a surplus of energy, while the hole diameter was significantly greater than the calibre of the projectile. For full metal jacketed bullet Lock Base there was the mean diameter at the input hole of about 12 mm with perpendicular impact, while the calibre of the projectile is 8.6 mm. The bullet Scenar with internal cavity creates the maximum dimension of an irregular opening about 20 mm. This is somewhat surprising in view of the design of bullet, which is not optimized in terms of armour piercing properties.

In all cases where the bullet 338 LM penetrated the plate, there occurred a huge cut out of the plate. The bullet itself has spread on small fragments with exception of small segment of the rear part of the bullet that burst through the plate. The full metal jacketed bullet penetrated the plate even when the impact angle was 15 degrees from perpendicular to the plane of sheet. The conditions of the angle of 30 degrees and 45 degrees did not allow the bullet to penetrate the plate, as shown in Fig. 2. The reason for this phenomenon is increasing the thickness of the sheet when penetrating in sloping trajectory and improving the conditions for slipping and ricochet of bullet from the front part of the sheet. In the supplementary experiment, it was verified that the limit angle of the impact projectile (measured from the perpendicular) is between 22 degrees and 30 degrees (22 degrees enables perforation, the angle of 30 degrees causes stopping down the bullet, respectively it causes pushing the bullet aside).

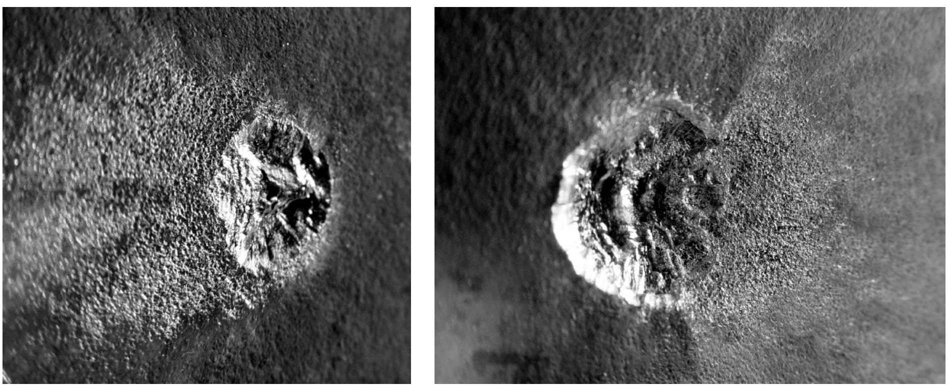

Fig. 2 Detail of the effect of full metal jacketed bullet of the calibre 338 Lapua Magnum at the front side of the plate of the thickness 10 mm (left - angle of the impact of 45 degrees – shot No. 6, right – 30 degrees - shot No. 7)

When shooting the projectile of the calibre 308 Win with the bullet HPBT (made by NORMA, 10.9 g), not a partial perforation occurred. Only a minor damage (shallow irregular nick) has been seen on the front plate – see Fig. 1, the position 4. On the back side of the sheet there were no apparent changes in shape. Therefore it can be stated that non-penetrating jacket bullet with lead core and with the impact energy of 3 000 J was stopped-down by the sheet metal of Hardox of the thickness of 10 mm with ease.

The experiments there further examined the ballistic resistivity of the sheet facing repeated impact by the ammunition of the calibre 308 Win/HPBT. Targeting point was still chosen in the same place and the same position was actually affected five times (max deviation of the centre points of each impact is only a few millimetres). Mean impact energy of the projectiles was 3 165 J. The metal was not penetrated even after the fifth round and the front side of the plate showed no major effects of depth (Fig. 3).

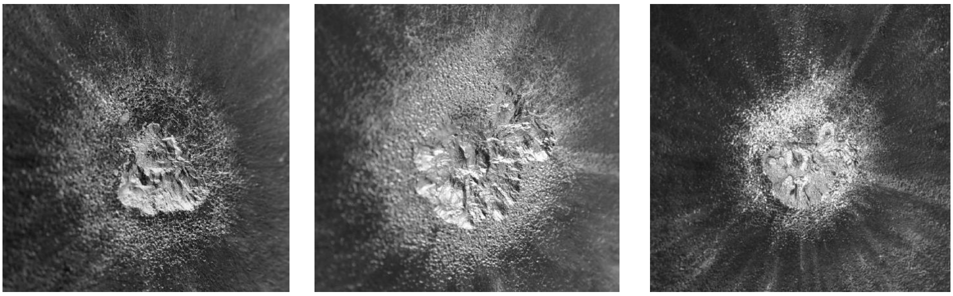

Fig. 3 Details of the front side of the plate of thickness 10 mm after the first bullet impact (left), third bullet (middle) and the fifth bullet (right) of the calibre 308 Winchester shot in the same place – experiment No. 3, shot No. 6

4. Analysis of Mechanism of the Sheet Metal Penetration

The sheet metal plate HARDOX is not directly intended for ballistic applications. Although having very good parameters in terms of mechanical properties, the ballistic resistance of armour piercing and non penetrating bullets of small arms ammunition is limited. Armour piercing bullets (i.e., bullets with armour piercing hard core) penetrate the sheet metal HARDOX at different mechanism as compared to non penetrating projectiles and less energy is required to penetrate the sheet metal.

The group of armour piercing bullets can include also such bullets which are partly or wholly made of hard materials (full bullets or bullets with tips – made from high strength steels). The impact of armour piercing bullet with tip leads to failure of the surface layer sheet by penetrating tip. The tip is separated (stripped) from the rest of the bullet and penetrates the sheet metal, while lead core and jacket remain in front of the target. The same mechanism of penetration is with the case of impact the sheet metal by the whole homogenous bullet (usually sub-calibre) made of high strength steel. Relatively good penetration ability can be achieved due to the quality of material and a small cross-section of the core, respectively a small cross-section of the whole sub-calibre bullet.

It is not the case with non penetration bullets whose design has not been optimized to achieve a high armour piercing performance. The group of non penetrating bullets can include also common shell bullets with cores made of soft material (for instance lead), which were used in testing or bullets of all-lead or brass design.

The impact of shell bullet with a lead core of the relatively low speed on a steel plate of sufficient thickness causes the deformation of the bullet and its gradual disintegration without any penetration or achieving the depth effect on the plate. In place of the impact of a bullet on plate just a surface plastic deformation occurs. If the target is used as armour with hard surface layer, the surface changes are negligible.

However, if the same bullet hits the target with over-limit high supersonic speed and thus it has relatively high impact energy, there occurs a deformation of the bullet in the first phase of the impact and the length of the bullet is reduced and it increases in diameter. As a result of high-energy bullet impact, however, the damage of the plate surface occurs, even if the plate has a relatively high hardness. The relatively compact shape of the bullet with a sharp tip helps to this process.

The bullet gradually penetrates into the depth of the plate, further distorts and in the front part degenerates (the diameter increases and the length of the bullet reduces, next drops off the eroding and fragmenting inside material of the bullet – lead). At the same time, the erosion of the plate material at the side of entry occurs and shooting channel also increases in diameter. These essential changes of ballistic process are therefore ideal for the bullet to be stopped down and not to penetrate the plate completely. There is not only increasing size of the bullet cross-section, but also the speed and the weight of the bullet significantly decreases and therefore extremely high decline in specific energy during the bullet penetration of the plate occurs. However, if the projectile impact energy is high, a shear failure of the rest of the plate takes place while achieving a certain depth of intrusions into the plate following by the massive cut out of the plate. This cut out is pushed forward by the deformed rest part of the bullet with similar diameter. The mean diameter of the shooting channel is thus much larger than the diameter of the impact bullet (to double).

In Fig. 4, there is a detail of the input shooting channel created by the bullet 338 LM Lock Base and the picture of the fragment with bullet residual.

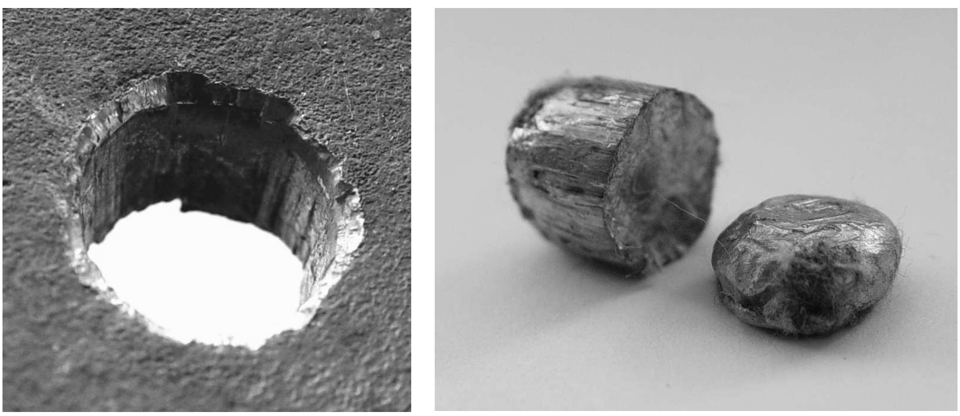

Fig. 4 Detail of the shooting channel in the plate 10 mm after shot of the rifle projectile with calibre 338 Lapua Magnum with full metal jacketed Lock Base (See the front of the plate, experiment No. 1, shot No. 2, left picture). In the right picture there is a cylindrical fragment with ogival face originated in the same experiment and shot. The fragment parameters: length 10.4 mm, mean diameter 12.5 mm and weight 7.62 g. The bullet residue parameters: length 5.6 mm, mean diameter 12.7 mm and weight 4.55 g.

A similar mechanism has been reported to penetrate sheet metal using both full metal jacketed bullet and expansion bullet with the cavity. Since the expansion bullet is easily distorted, a larger diameter of the shooting channel and cut out was achieved with respect to full metal jacketed bullet. With regard to the different shape of both cut outs it can be assumed that the cut out in Fig. 5 is only a part of the overall cut out, which is split into 2 parts (part 2 not found). The asymmetric shape of the cut out embossed out of the sheet by penetrating expansion bullet attests the considerable influence of radial forces on the entire terminal ballistic process.

Shooting experiments therefore have shown that if the bullet has enough energy at the impact on a plate or certain thickness, the bullet penetrates the plate fully, even in case of an extremely large difference in hardness and strength of target and bullet materials (hardness of the plate HARDOX 450 is significantly higher than the hardness of lead). Therefore, the bullet design almost does not determine the armour piercing ability with high impact energy.

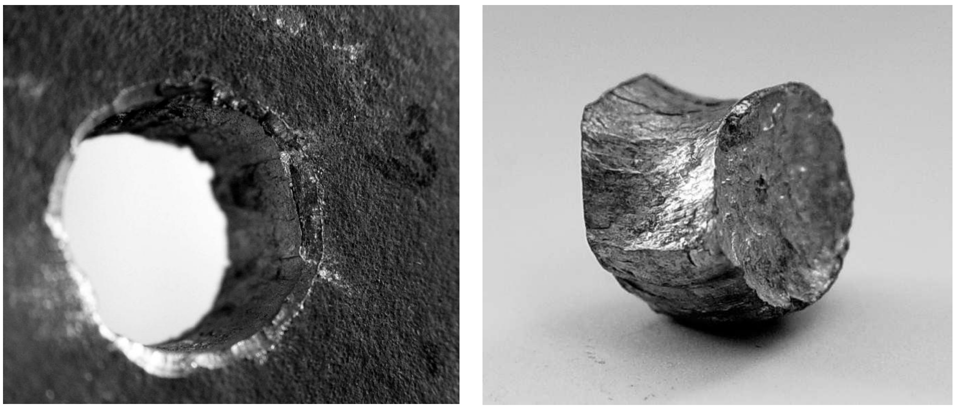

Fig. 5 Detail of the shooting channel in the 10 mm plate after shot of the rifle projectile with calibre 338 Lapua Magnum with expansive bullet Scenar (See the front of the plate, experiment No. 1, shot No. 3, left picture). On the right picture there is a steel fragment with those parameters: length 10.2 mm, mean diameter 19.2 mm and weight 11.3 g. The bullet residual was not found.

5. Simulation

5.1. Introduction

Next step of the work is to create a simulation of the bullet penetration through the target material using finite element method (FEM). The goal is to find consensus between experiment and simulation. FEM provides a tool to study the process more in detail, to investigate the influencing factors, to predict the impact behaviour and reduce the number of needed experiments.

Two models of the bullets of calibre 338 Lapua Magnum – Lock Base and Scenar – are introduced penetrating the HARDOX 450 sheet plate of the thickness of 10 mm in accordance with experiments mentioned above. The bullets are of a two-part design with the lead core and a gilding metal (tombac) jacket. The mass of both bullets is of the same value of 16.2 g and the diameter is of calibre 338 (which means 8.58 mm).

The bullet Lock Base is a full metal jacketed kind with the length of 35.3 mm and the bullet Scenar is expansion jacketed hollow point kind with the length of 39.8 mm. The rectangular dimension of the experimental target plate is 400 mm × 400 mm, the diameter of the simulation circular target plate is 200 mm and the whole perimeter is clamped.

5.2. FEM Model

All FEM models were prepared using the explicit non-linear transient dynamic numerical code Ansys Autodyn v11.0 with 2D symmetry so only a half of all parts were modelled. The simulation methodics is taken from [2] and [3]. The model of the bullet was created upon the real geometry with equal dimensions. The density of the lead core and gilding metal jacket was modified to achieve also equal weight of the bullet. The bullet Scenar has a hollow in the front of the bullet and the incendiary in this hollow is neglected. The geometry of both bullets was a little bit simplified in respect with creating the suitable mesh. The character and discretization of the model of the bullet Lock Base and Scenar both with the target plate are shown in Fig. 6.

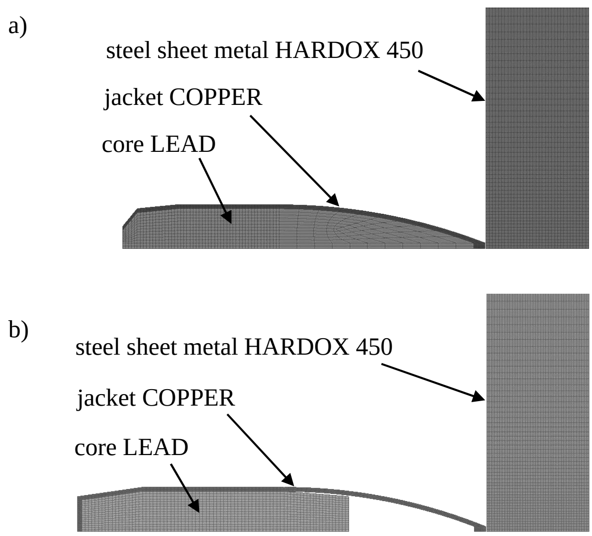

Fig. 6 FEM model of Lock Base (a) and Scenar (b) bullets with target

All material models for the bullet and the plate were retrieved from the Autodyn material libraries [4] due to the fact that there is still limited published data available on the dynamic material properties of used materials. Material characteristics were therefore a little bit modified to achieve desirable behaviour of the target and the bullet. The material data are equal for the both bullets Lock Base and Scenar with exceptions mentioned in the text below.

A shock equation of state and a Steinberg-Guinan constitutive model [5] were used to simulate the material response to dynamic loading of the target plate. The sheet metal HARDOX 450 is represented by the modified material model STEEL V250 taken from Autodyn library using the following basic parameters: density 8 129 kg·m^{-3}, Gruneisen coefficient 1.6, parameter C1 3 980 m·s^{-1}, parameter S1 1.58, reference temperature 300 K, specific heat capacity 408 J·kg^{-1}·K^{-1}, shear modulus

71 800 MPa, yield stress 1 560 MPa, maximum yield stress 1 600 MPa, hardening constant 1, hardening exponent 0.5, melting temperature 2310 K. A failure model considers plastic strain of the value 0.5 for the bullet Lock Base and of the value 0.05 for the bullet Scenar. Erosion geometric instantaneous strain is 1.1.

The lead core is represented by Autodyn model LEAD and uses a shock equation of state and the Steinberg-Guinan constitutive model. The lead material uses the following modified basic parameters: modified density 11 360 $kg \cdot m^{-3}$, Gruneisen coefficient 2.74, parameter C1 2 006 $m \cdot s^{-1}$, parameter S1 1.429, reference temperature 300 K, specific heat capacity 124 $J \cdot kg^{-1} \cdot K^{-1}$, shear modulus 8 600 MPa, yield stress 8 MPa, maximum yield stress 10 MPa, hardening constant 27 MPa, hardening exponent 0.52, melting temperature 760 K, no failure model, erosion geometric instantaneous strain 4.

The jacket made of gilding material uses the COPPER Autodyn material model with shock equation of state and a Piecewise Johnson-Cook constitutive model. The jacket modified basic parameters are as follows: density 8 800 $kg \cdot m^{-3}$, Gruneisen coefficient 2, parameter C1 3 958 $m \cdot s^{-1}$, parameter S1 1.497, reference temperature 300 K, shear modulus 46 400 MPa, yield stress 1 200 MPa, effective plastic strains 0.3 and 1, thermal softening exponent 1. A failure model considers plastic strain of the value 0.4 and erosion geometric instantaneous strain is 2.

The actual bullet speed before the impact of the target is not known, so therefore the value 880 $m \cdot s^{-1}$ is considered for FEM simulation upon the Tab. 1 for both kinds of the bullet. The initial gap between the bullet and the target is 0.1 mm due to the simulation requirements.

The evaluating parameter of correlation between experiment and simulation is the character of penetration, the size of cut out in target material and dimensions of the bullet residue and the target fragment.

5.3. Results of Simulation

During the dynamic process of bullet impact, the bullet penetrates the sheet metal and a large target deformation and material fragment occurs for both bullets in FEM simulations. The bullet penetrates the plate with massive change of its shape and the jacket is stripped off from the core. Exemplary simulation penetrations are presented in Fig. 7 for the HARDOX 450 target and both kind of bullets, see also [6].

Both bullets have a little bit different process of penetration. The bullet Lock Base has a whole solid core and therefore the penetration is focused more in the middle of travelling trajectory. On the other hand, the bullet Scenar is of expansive sort with the cavity in the tip so the bullet jacket expresses much larger deformation in this tip. The larger deformation on the tip makes the face of the bullet more flat, therefore a larger cut out occurs. In spite of this, the bullet has a surplus of energy to penetrate the target. The shear occurs with target material at the end of the penetration process and a target fragment is pushed outside of the hole by the residual of the bullet.

During the penetration process a loss of bullet and target materials occur caused by using the erosion option for this purpose in the simulation.

5.4. Comparison with Experiments and Discussion

The character of penetrating process is similar to experiments for both the bullets. The bullets penetrate the target with a surplus of energy. The character of deformed bullet and the plate is similar as well. The planar deformation of the face side of the sheet metal is neglected.

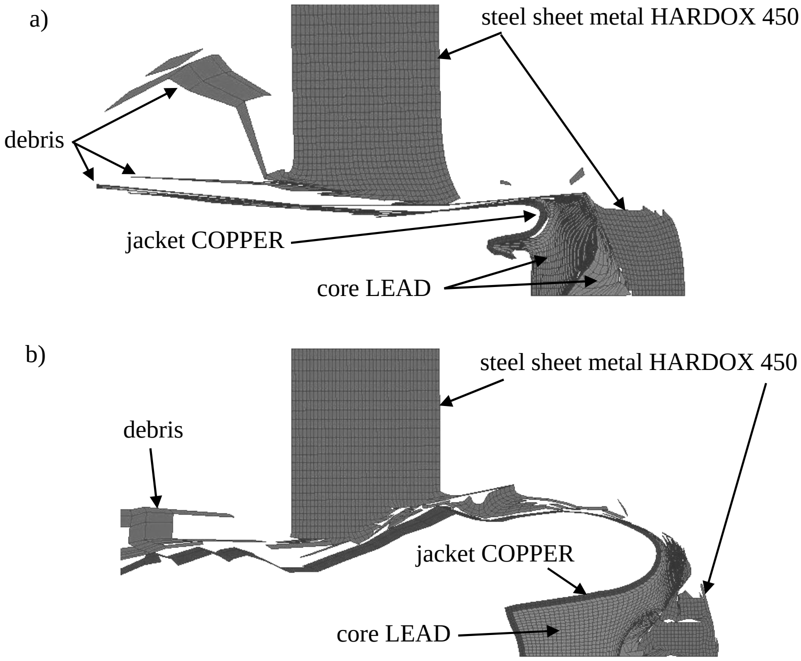

Fig. 7 The target and the bullet after penetration for Lock Base (a) and Scenar (b)

The evaluating parameter is the diameter of the hole made by bullet. The results show very good consensus in terms of diameter of the hole in HARDOX sheet metal plate and not so good consensus with the bullet residue and the target fragment. The results are shown in the Tab. 2.

Tab. 2 A comparison of the parameters of the experiment and the simulation

Bullet		Lock Base (FMJ)		Scenar (HP)	
		exp	sim	exp	sim
Parameter		[mm]	[mm]	[mm]	[mm]
hole in target	diameter	12.5	12.5	20.4-19.0	15.1-20.0
bullet residue	mean diameter	12.7	14.1	–	up to 15.5
	mean length	5.6	5.9	–	10.0
target fragment	mean diameter	12.5	11.8	19.2	4.2
	mean length	10.4	4.7	10.2	4.2

The experimental and simulation diameter of the hole in the target is consistent with the bullet Lock Base (the value 12.5 mm, experimental value is in accordance to Fig. 1, point 2). The penetration of the bullet Scenar is more complex. The experiment reports in Fig. 1, point 3 a creation of conical hole with the mean diameter of the inlet 20.4 mm with unilateral narrowing to 19 mm. The simulation shows the opposite direction of the conical hole and much smaller input diameter. Also the chamfer was not achieved in simulation that occurs for both experimental input holes shown in

Fig. 4 and Fig. 5, both left. More precise simulation results require a deeper investigation of actual material characteristics.

The bullet residue is consistent with Lock Base in terms of the mean diameter and the mean length. The Scenar bullet residue was not found, so comparison to the simulation is not possible.

Regarding to the target fragment, the comparison of the experiment and the simulation shows only partial agreement. The mean diameter of the Lock Base target fragment is consistent, the rest of the comparing parameters is not consistent.

According to authors' opinion, the numerical model is acceptable, but material characteristics should be modified. The difference between the experimental and numerical results is also due to some of the uncertainties that exist with the numerical model. For example, chosen models are supposed to be similar to the actual material used in experiments. Next influencing factor is neglecting the drag of the air for travelling bullet and the void is considered. For numerical purposes is initial gap between the bullet and the target is considered to be of the value 0.1 mm without experimental distance 10 m. Next influencing factor is boundary conditions. In the simulation the target perimeter is clamped. On the other hand, mounting plate for the experiment may have some flexibility. Next factor is the speed of fired bullets on experiments. Their actual value before and after penetration can help to precise the results. And finally, the actual experimental shape of penetrated plate was rectangular and the shape used in simulations is circular. Also the location of the bullet impacts of the experimental plates was different with regard to the simulation.

6. Conclusion

The experiments carried out in the field of terminal ballistics have found out that the sheet metal plate HARDOX 450 of the thickness of 10 mm does not meet ballistic resistance to impact of non penetrating bullets with impact energy of 6500 J in the perpendicular line and slightly sloping direction of the impact (up to about 25 degrees from perpendicular line to the plane of sheet). The plate of mentioned thickness is able to safely stop non penetrating bullets with impact energy 3 000 J to 4 000 J (depending on calibre) and non penetrating bullets even with the impact energy to 6 500 J in sloping direction. However, the plate is not capable of withstanding the impact energy of 3 000 J and more using armour piercing bullets.

Next a numerical model has been developed that simulates the penetration and subsequent perforation of the sheet metal HARDOX 450. The Autodyn material library contains suitable alternate material models and some modification is needed to achieve a better correspondence between experimental and simulation results. It is necessary to conduct required dynamic testing of materials of interest to provide correct inputs for constitutive material models. Nevertheless, used models can still provide a useful insight into the penetration mechanisms and they provide a tool for the analysis of the armour structures with bullet impact.

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